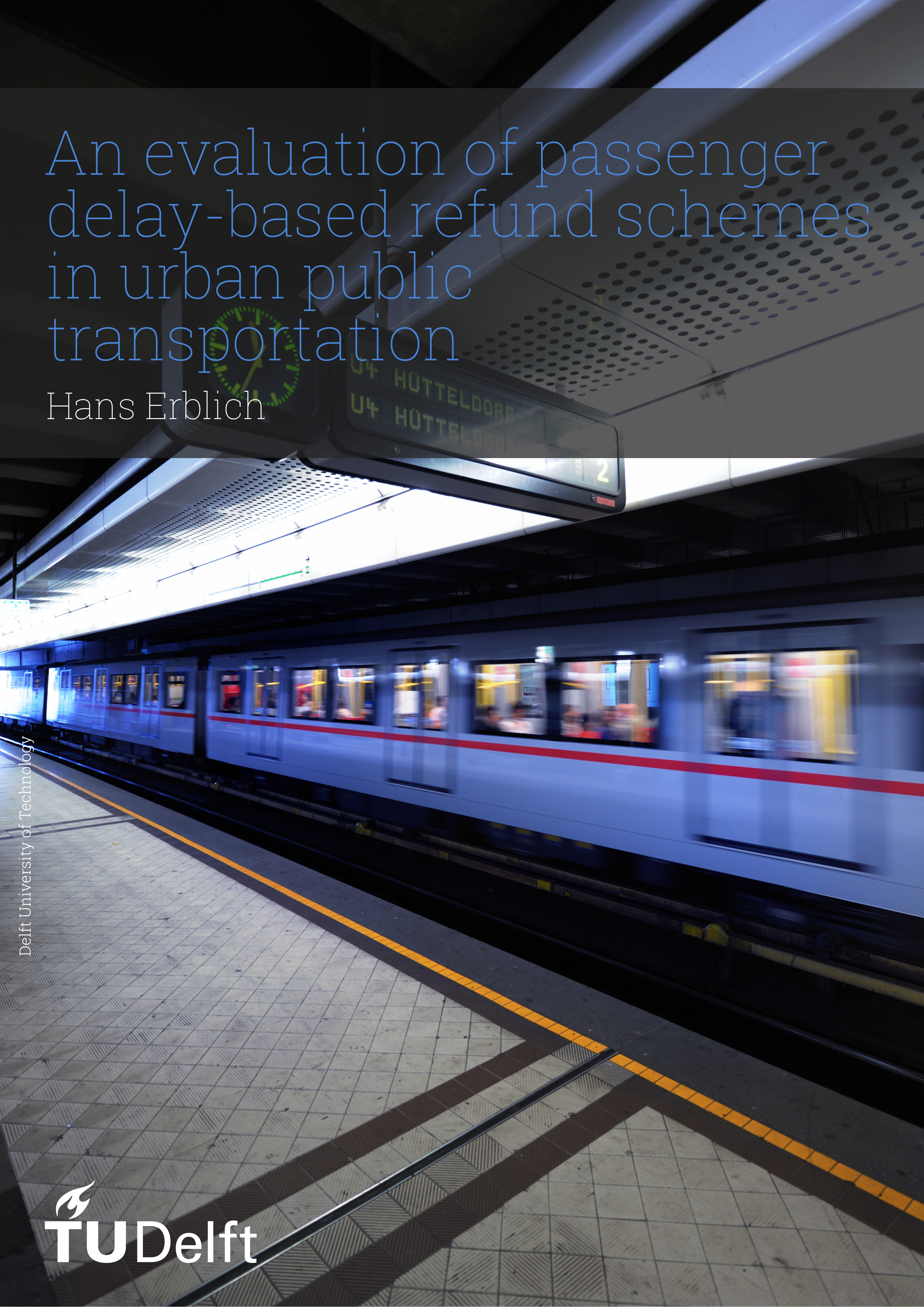
An evaluation of passenger delay-based refund schemes in urban public transportation

Hans Erblich



Delft University of Technology

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An evaluation of passenger delay-based refund schemes in urban public transportation

by

Hans Erblich

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Preface

With this thesis, I present the work to the world with which I aspire to finish off my studies at the Delft University of Technology. These six years have always been an utterly inspiring journey for me, not just because of the knowledge gained on civil engineering or transportation topics, but also because of the progress I made as a person in that time. I have always been eager to shed light on underexposed topics, such as in my bachelor thesis which compared viewpoints on a somewhat underexposed road traffic phenomenon, and I now hope to do the same with this thesis, which addresses a topic about which - to the best of my knowledge - literally no scientific literature has ever been written.
Of course, I could not have created this thesis without the help of many people, to whom I owe a large debt of gratitude. To start with, I would like to thank the three members of my thesis committee: Jaime Soza-Parra, for our many progress meetings, your detailed reviewing, your new and always inspiring ideas and your general positive outlook and confidence, Panchamy Krishnakumari, for your clear reasoning, your former research that partially made this thesis possible, and the massive help you gave me by providing its data and codebase, and Oded Cats for your targeted yet holistic feedback, your keen eye for detail and your enlightening viewpoints on matters I found myself occasionally stuck on.
Finally, I would like to thank all my dear friends, family and peers for your confidence, renewed perspectives and interesting talks about this subject. I especially would like to thank three people: Brendon, for thinking along about the data processing, for your help with the cover, and for proofing the completed work, Jeremy, for your amazing help with some programming-related issues, and my love Unnur, for unconditionally supporting me through highs and lows, and for being exactly the person you are.

Hans Erblich
Rijswijk (ZH), November 2023

Executive summary

The post-purchase experience is considered one of the stages of customer experience (CX). For a public transport customer, a way to improve this post-purchase experience could be issuing a refund when the customer has experienced a delay. To achieve this, several public operators have a refund scheme in place. Next to improving the aforementioned post-purchase experience, other reasons to have such a refund scheme in place could be a financial incentive for public transport operators to maintain their punctuality standards, or a proof of confidence to customers that they can safely assume to reach their destination in time. Nevertheless, to the best of knowledge, no research seems to have been carried out yet on several aspects of these refund schemes, such as which design considerations can be taken into account upon establishing one, or how their performance can be evaluated. To add to the knowledge on this topic, the objective of this research is defined as follows: *Quantify the functioning of passenger delay-based refund schemes, and outline the ways in which their impacts can be assessed for both travellers and policymakers in public transportation*.

To start with, the state of the practice was reviewed by surveying the internet and the information that is being provided by the individual public transport operators, as well as by sources such as newspapers or other websites. By categorising this information, patterns of information could be derived, such as certain characteristics that return in various ways within the different refund schemes. These characteristics served as a start for the design aspects of these refund schemes, which can be found in the conceptual framework in Figure 1.

In this conceptual framework, the **properties** are elements that are part of a refund scheme, upon which a public transport operator can actively exert influence. The **variables** are the elements that determine the eventual refund given but are not determined by the public transport operator, at least not considering the refund scheme. Finally, the **outputs** show the end product that the user receives.

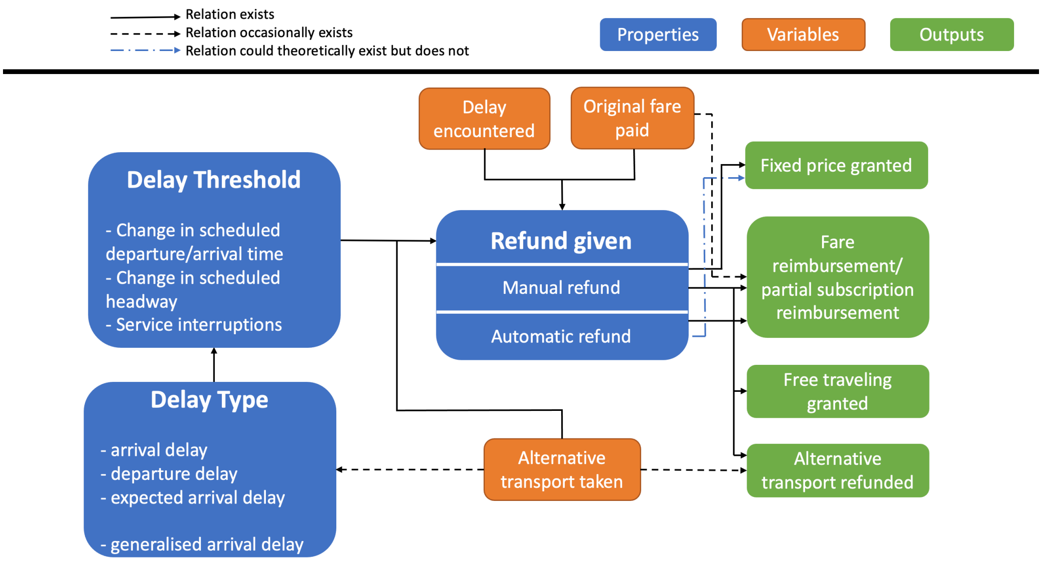

Figure 1: Conceptual framework for designing a delay refund scheme

This conceptual framework yields the design aspects of refund schemes, which are defined to be the delay type, delay threshold, refund type, and the inclusion of alternative transport. Next to these refund scheme design aspects, a number of additional findings are addressed as well. These include the findability of refund schemes, which, although not directly a characteristic of a refund scheme, its functioning can be assumed to be affected by it. Whereas for some cities the refund scheme is clearly shown on the main page of the website of the operator, operators in some other cities hardly mention

the refund scheme on their website, with the refund scheme merely being described in their general terms and conditions, for instance.
Generally, refund schemes consider the refunding of a single trip that has been delayed. However, the refund scheme of the RER in the Paris metropolitan region is strongly deviating from this: it refunds a part of a seasonal subscription ticket to all passengers owning one, that live in a certain radius of a line of which the punctuality dropped below a certain threshold.

To carry out the remainder of the analyses to be discussed below, the following is needed: passenger tap in/tap out data, rail movement data, as well as the scheduled travel time between every station. Using this data, an analysis could be carried out which is based on the delay component estimation methodology as found in Krishnakumari, Cats, and Lint (2020). This methodology uses the commonality of trips, i.e., multiple trips that can be assumed to have been taken on the same vehicle, to create a system of equations, solved by linear regression, which yields for every trip taken its three components that make up a total delay: its initial waiting time delay, its vehicle delay and its transfer delay. Because individual passengers' possibly erroneous behaviour can be filtered out in this way, the results can be expected to increase in reliability compared to when using experienced observations. Furthermore, it enables determining the departure delay, i.e., the delay encountered at the start station of the trip, and arrival delay, i.e., the delay that has been accumulated by the end of the trip, of every trip taken during this study period.
The methodology described above was applied to approximately a year of data from the Washington Metro, between August 2017 and August 2018. During this study period, a total of 157,355,823 trips was taken, of which the departure and arrival delay counts are shown in Table 1. The departure delays are generally smaller than the arrival delays, although this can easily be explained by the summative nature of the departure and arrival delay estimate calculations: a trip will using this calculation method always have a smaller departure delay than its arrival delay.

Delay (min)	**Departure delay #trips (%)**		**Arrival delay #trips (%)**	
<1	128,680,750	(81.8 %)	94,994,850	(60.4 %)
1-5	26,709,424	(17.0 %)	54,929,729	(34.9 %)
5-10	1,703,153	(1.08 %)	5,297,186	(3.37 %)
10-30	251,756	(0.16 %)	2,021,668	(1.28 %)
30-60	9,087	(0.006 %)	103,456	(0.066 %)
>60	1,663	(0.001 %)	8,944	(0.006 %)

Table 1: Counts for the departure and arrival delay distribution during the study period

Using the departure and arrival delay for every trip, as well as the origin and destination station for every trip and the corresponding fare, the amounts of refunds paid can be determined, using the refund scheme that was originally used by the Washington metro operator WMATA. This refund scheme automatically reimburses the fare paid for the journey back onto the smart card of the passenger, when they have experienced an (arrival) delay of over 10 minutes. By aggregating the delays for all trips during a day as well as the amounts of refunds, both the number of refunds and the monetary amounts, given during a day, a number of scatterplots are obtained. It could be concluded that there is indeed a strong linear effect between these two (delays and refunds), which is further confirmed by the fact that a regression analysis yielded p-values well below 0.05. The scatterplots showing the aggregated data points for every day, normalised for the number of trips taken, as well as the regression slopes, can be found in Figure 2 (for the amounts of refunds *paid*) and Figure 3 (for the amounts of refunds *given*). For the former, a distinction is made between weekdays and weekend days, because the fares paid on these days and as such the number of refunds is considerably different.
This discovered linearity between delays and refunds could be relevant for a number of cases, for instance when considering different detour scenarios with corresponding delay predictions. The subsequent refunds could for instance also be calculated in this way. It should be noted, however, that the slope of these lines cannot directly be copied to other cities and situations but will depend on factors like the network and the refund scheme chosen.

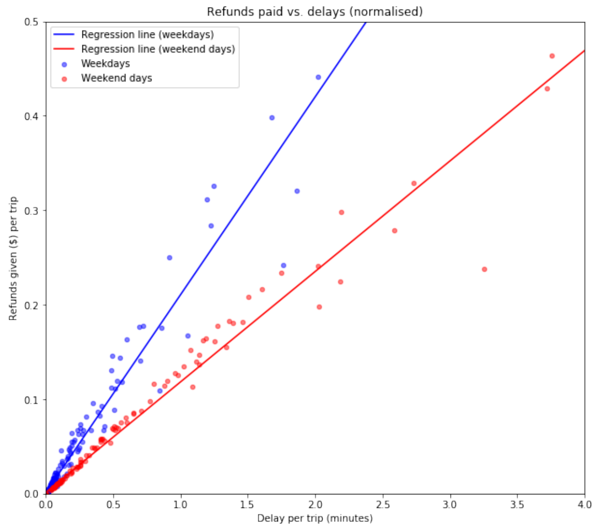

Figure 2: Link between delays and refunds, discerning between weekdays and weekend days, with regression slopes added

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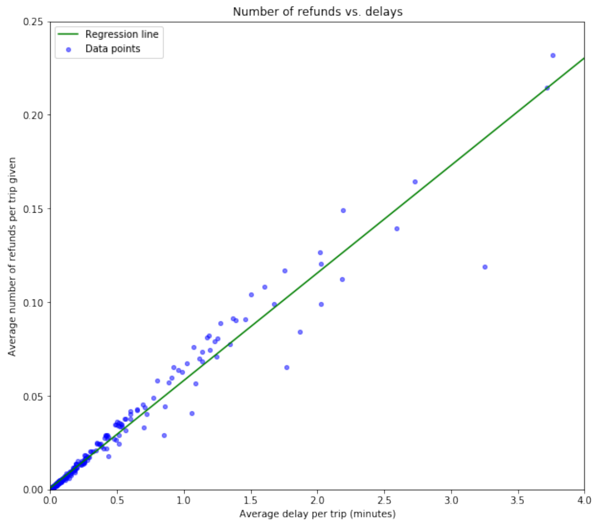

Figure 3: Link between delays and number of refunds, with regression slopes added

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Next to the analysed link between delays and refunds, a set of key performance indicators (KPIs) was established which allowed assessing the performance of a refund scheme, as well as comparing the performance of different refund schemes. The KPIs include:

- the refunds per trip (RPT), which divides the number of refunded trips by the total amount of trips
- the Delay Ratio (DR), which divides the average delay of all refunded trips by the average delay of all trips
- the revenue losses (RL), which divide the amounts of refunds paid to the passengers by the total revenue generated by passenger trips
- the time loss compensation share (TLCS), which use a certain Value of Time to determine which percentage of passenger time losses is compensated by issuing refunds.

These KPIs were applied to a set of set of synthetic refund schemes. This set of refund schemes used the aforementioned original refund scheme used by the Washington Metro operator WMATA as a basis, however, the parameters were varied according to the design aspects that were established from the aforementioned survey. The parameters that were varied include the delay threshold, the type of delay, and the form of payment. Furthermore, the set of refund schemes also includes a refund scheme as found in the Paris metropolitan region that uses the general punctuality on a line and subsequently refunds all travellers that can have been expected to be affected by a possible drop in this punctuality.

Using these KPIs, conclusions could be drawn on the performance of different refund schemes, mainly regarding the sensitivity of every refund scheme to its delay threshold. For instance, the sensitivity to the delay threshold seems to be stronger for departure delay-based refund schemes than for arrival delay-based refund schemes. However, the sensitivity to the delay threshold seems even larger when considering the aforementioned 'generalised' punctuality refund schemes. When considering refund schemes using arrival delay rather than departure delay, the refund schemes using departure delay seem to represent time losses somewhat less accurately. However, this could change significantly when some factors are included that have not been able to be incorporated in this evaluation, such as alternative transport.

The main contributions of this thesis to the scientific literature are twofold. Firstly, an overview has been created of parameters and design aspects that are currently in use for passenger delay-based refund schemes in urban public transportation. Furthermore, a methodology has been developed to evaluate the performance of these refund schemes, as well as guidelines which could help determine an optimal refund scheme, dependent on the network, fare and refunding properties.

To further reduce the research gap that has been discovered throughout this thesis, a number of additional research topics could be considered. Firstly, with this data setup, the inclusion of alternative transport refunding in a refund scheme is not possible. Hence, additional research could focus on the most appropriate ways to integrate alternative transport in cases where this can be relevant, such as service interruptions. Furthermore, with the delay component analysis methodology, there is for some trips in the data a considerable discrepancy between the estimated delays and the experienced delays. To improve knowledge on this discrepancy, new research could examine the link between individual passenger behaviour and their registered tap-in/tap-out behaviour, by for instance taking their walking routes into account. This could increase the insights into the ways that delays encountered on public transport vehicles eventually affect the passengers using them, as well as factors like crowding. A final research gap relates to the *goals* of refund schemes, such as possibly increasing the post-purchase customer experience, creating a financial incentive for public transport operators to maintain their punctuality goals, or acting as a proof of confidence to show customers that their destination can be assumed to be reached in time. Despite the analyses of refund schemes and their performance evaluation carried out in this thesis, these do not cast any light on any of these topics which are as such still research gaps. For this reason, a survey amongst public transport users would be one of the starting points to better understand how public transport customers respond to a refund scheme in use. The findings of this survey could possibly be coupled with the KPI's defined and tested in this research, which would enable one to monitor and/or predict customer satisfaction ratings. This could serve as a start for better aligning customer expectations with customer service, which can be considered the main goal of a refund after a delay.

Contents

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1 Introduction

1.1. Background and motivation

Over recent years, the significance of customer experience (CX) in public transportation has undergone a surge in attention. This increased attention can be expected to originate from several factors. To start with, the role of public transportation itself in society has gained more relevance. One of the driving factors behind this could be the increased feeling of urge towards a greener society, of which it is believed that public transportation can be a significant factor in this transition. Also, with the rise of social media, it is easier for complaining customers to let themselves be heard, which might in turn be a deterrence factor for other passengers from using that particular operator. In recent years, we can see a growing trend in initiatives to improve CX, such as the Dutch OVKB (OV Klantenbarometer, or public transportation customer barometer) which has since 2018 been monitoring the customer experience in public transportation as well as trends unfolding amongst the CX of different operators (OV-Klantenbarometer (2023)). In the United States, a myriad of CX programs initiatives have been launched parallel to each other in various cities, which are for instance summarised in Weinstein (2023).
Post-purchase experience is considered one of the stages of CX (Jain, Aagja, and Bagdare (2017)). Adequate compensation when delays occur could be considered a part of this post-purchase experience for a public transport traveller. To this end, when delays occur in public transportation, several public transport operators have a refund scheme in place. The goal of this refund scheme is to grant some form of refund to passengers who have experienced a delay whilst travelling on (a) vehicle(s) of that particular operator. There might be several reasons for this practice. Firstly, passengers who have received a substantial delay might consider themselves better heard. Having a refund scheme in place could therefore increase passenger satisfaction. Also, a refund policy could act as a financial incentive for the public transport operator, for them to put effort into maintaining their punctuality goals. It could also act as proof of confidence, to show the customers that they can safely assume to reach their destination in time.
Whilst we can safely assume that these schemes will have a certain effect on the CX, we could not find any (scientific) literature on these delay-based passenger refund schemes, regarding aspects like the current state of the practice, i.e., which forms of refund schemes currently exist, as well as their purpose, i.e., customer satisfaction improvement, compensating time losses, etc. The literature search was carried out by searching for scientific literature, more specifically considering general information on refund schemes and how to design them. To achieve this, the search queries ‘public transport’ or ‘metro’, ’delay’, and ‘refund’ or ‘repay’ have been used to search databases such as Scopus, ScienceDirect, Springer, Taylor & Francis, SAGE Journals, IEEE, and Google Scholar. However, as mentioned, no literature was found, even upon relaxing the ‘metro’ criterion and considering all rail-based public transport, i.e., also including (inter)national train systems. The mere reference to specifically refund schemes was found in Yap (2020), but the only information that was provided there was the fact that public transport disruptions can cause revenue losses due to the existence of delay refund schemes.
Moreover, although it can reasonably be expected that design choices need to be made for establishing these refund schemes, no literature was found on aspects such as how they are established, nor the ways in which their performance can be evaluated. Finally, with refund schemes that make use

of smart card data rather than specifying a specific trip that was originally planned to be taken, it can be questioned what the exact 'contents' of an experienced delay are, in terms of delay sources like vehicle delay or transfer delay, as information about the (delays of the) vehicles used on the trip cannot be expected to be always available.
Increasing the knowledge on these topics could lead to policymakers of transport authorities and/or public transport operator planners making more informed decisions as to which factors to incorporate and to account for in their refund schemes, as well as the ways in which they can evaluate the functioning of their refund schemes. This could be part of a more targeted way of increasing passenger satisfaction, or at least more familiarity with ways in which this could be achieved.

1.2. Research objective and research questions

To clarify some of the issues raised in the preceding section, we define the objective of this research as follows:

> Quantify the functioning of passenger delay-based refund schemes, and outline the ways in which their impacts can be assessed for both travellers and policymakers in public transportation.

The main research question that will be answered in this research is the following:

> How can the current state of practice be used when designing passenger delay-based refund schemes with rail-based urban public transportation systems, and how can their performance be assessed?

In order to answer this research question, we have defined several sub-research questions divided into three main topics, which we will define below:

> 1a) Which forms of passenger delay-based refund schemes are currently existing in urban public transportation?

This research question aims to determine the state of the practice, or which refund schemes are currently in use and which aspects are varied among the currently extant refund schemes. The aspects that are varied form the basis for the next sub-research question:

> 1b) What are the design aspects of creating urban public transportation delay-based passenger refund schemes?

This research question mainly focuses on establishing the parameters that can be used for the decision-making process when creating a refund scheme.

The second main topic focuses on fusing passenger smart card data (i.e., tap in and tap out data) with schedule information, in order to obtain a disaggregate (i.e., on an individual passenger level) overview of delay components that passengers have experienced during a trip. The aforementioned data originates from the metro of Washington D.C., about which more information will be provided in chapter 5. Using this data analysis, the following research question can be answered:

> 2) To what extent is there a relation between total passenger time losses and refunds granted?

As the third main topic, the information from both of the main topics will be fused by performing a parameter sensitivity analysis on refund schemes, by testing it to actual Washington D.C. trip information as also used under the second main topic. In order to perform this analysis, we first need to define a set of key performance indicators (KPIs), with which the functioning of the previously defined refund schemes will be evaluated. This will enable us to answer the following research question:

> 3a) Which indicators can be used to assess the performance of different delay refund schemes?

Finally, these indicators will be used to assess the performance of different delay refund schemes of which the parameters vary, which enable us to answer the following research question:

> 3b) What is the impact of different delay refund schemes given a fixed input of trips?

More details on the exact methodology will be provided in chapter 2.

1.3. Report structure

The structure of this report is as follows. After the introduction in chapter 1, chapter 2 elaborates on the methodology for carrying out the research. In chapter 3, the results of the survey are presented, with which Research Question (RQ) 1a can be answered. Subsequently, following from the survey, several design aspects of refund schemes are established in section 4.1, enabling to answer RQ 1b. In section 4.2, the KPIs for evaluating the performance of these refund schemes are presented, which partially enable to answer RQ 3a. In chapter 5, the case study and its data are introduced (section 5.1). Also, the refund schemes that will be used in the case study are presented (section 5.2). Furthermore, some descriptive statistics will be provided on the case study data (section 5.3 and section 5.5). Also, the effect of the way in which the delays are estimated is presented (section 5.4). Subsequently, in chapter 6, the results of the case study are discussed. In section 6.1, the results of the delay/refund proportion analysis are discussed, with which RQ2 can be answered. Finally, in section 6.3, the created refund schemes are applied to the case study travel data and are evaluated according to the aforementioned KPIs. In this way, RQ3a and RQ3b are answered. To finish off, chapter 7 provides some discussion points as well as the conclusions that could be drawn from this research.

2 Methodology

In order to answer the research questions that have been defined in the preceding chapter, a total of three major analyses are carried out, of which the third analysis will follow from the (results from the) first two analyses. The first analysis is the survey. This yields both the state of the practice, as well as the design aspects that can be used when designing refund schemes. The second analysis is the delay component analysis, of which the core is a regression analysis to estimate the components of which a delay consists. This also enables us to investigate the link between delays and refunds given. Finally, the results of the aforementioned two analyses are combined to create refund schemes, which use as input the results of the delay component analysis and are evaluated according to a number of key performance indicators (KPIs) established.
To make this approach clearer, it is summarised in the following flowchart in Figure 2.1. The numbers between square brackets indicate the chapter in which the respective deliverable or input is explained.

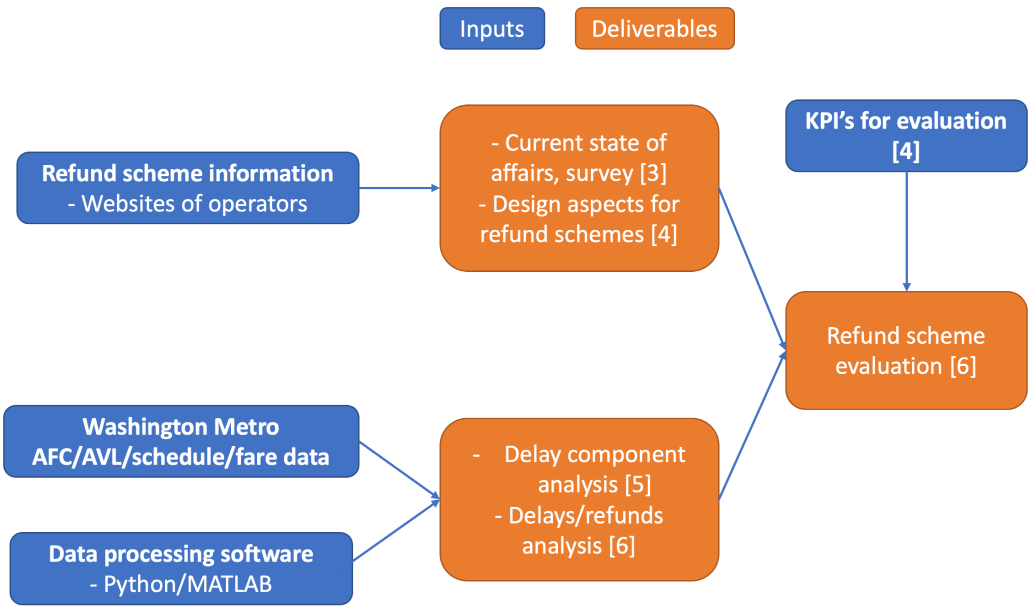

Figure 2.1: Flowchart for methodology

The remainder of this chapter is organised as follows. In section 2.1, we will outline the data requirements, i.e., the minimum information that the data needs to contain in order to execute the methodology as described later on. In section 2.2, the methodology to estimate the different components of a delay will be explained, as well as the way in which this will be used in the subsequent analyses. These analyses are the link between delays and refunds, of which the methodology will be explained in section 2.3, as well as the refund scheme evaluation, of which the methodology will briefly be explained in section 2.4.

2.1. Data requirements

For the subsequent analyses, to be described in the sections below, the data that we need for it is subject to a number of requirements.

Firstly, we need passenger trip information data. This data should at least contain the tap-in location and tap-out location of the passenger, along with the corresponding timestamps. These timestamps are vital to determine the travel time of the passenger at a later stage. For this reason, public transportation systems which merely require a tap-in are unsuited for this type of analysis, as – even with route inference methods – the exact travel time can then not be determined.

Also, actual rail movement data should be available, i.e., the locations and arrival/departure times of every vehicle at every moment in time. It should also, possibly superfluously, be noted that the rail movement and passenger movement data should stem from the same time period.

Furthermore, there should be information available regarding the scheduled travel time between stations. This enables comparing the scheduled travel time to the actual travel time.

Finally, network information should be available, i.e., the nodes and links through which vehicles can traverse.

2.2. Delay Component Analysis

To evaluate refund schemes and how they perform according to a number of key performance indicators under different forms of delay, we need to obtain estimations on delays that passengers encounter whilst travelling. We can distinguish departure delay, i.e., the delay that a passenger has experienced at the origin of their journey, and arrival delay, i.e., the delay that a passenger has experienced at the destination of their journey. To get to these two types of delay, we largely use the approach used by Krishnakumari, Cats, and Lint (2020), albeit with some extended post-processing in the output. We will elaborate on this approach in the following section. The approach has also been summarised in the flowchart following in Figure 2.2.

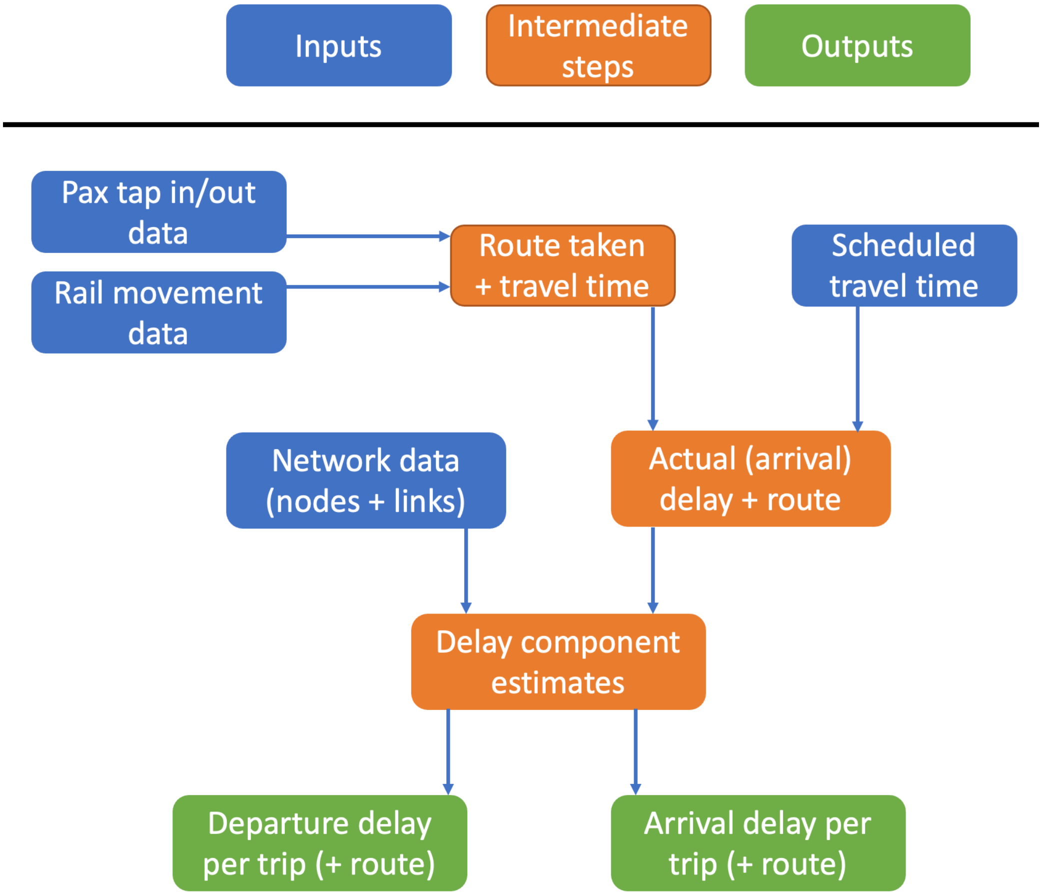

Figure 2.2: Flowchart for delay component estimation

2.2.1. Component estimation methodology

By using the ODX method (standing for **O**rigin, **D**estination and Transfer (**X**)), which is described in more detail by Sánchez-Martínez (2017), we can infer the path that was taken at every passenger's journey, given that both the origin tap-in and destination tap-out location are available, next to timestamps for these tap-in and tap-outs. Subsequently, we compare the scheduled travel time from origin to destination to the experienced travel time, which yields the (experienced) arrival delay per trip taken. We use this experienced arrival delay for further processing.

The arrival delay of a single passenger can, in accordance with the definitions used in Krishnakumari, Cats, and Lint (2020), be decomposed into the initial waiting time delay (the delay that a passenger experienced whilst waiting for their vehicle to arrive), the track segment delay (the delay that a passenger experienced whilst travelling on a certain vehicle), and transfer delay (the delay that a passenger experienced whilst waiting for their transfer, if applicable). For passengers travelling the same route on the same vehicle(s) at the same time, it is more likely that the delay(component)s that they experienced are similar. Therefore, by generalising all passenger trajectories, and all their encountered delays in matrix form, we obtain a system of equations for every time aggregation chosen. We use a time aggregation of 30 minutes, in line with the original methodology. We can find a solution to this system of equations in the form of a constrained linear least square solution. This yields the combination of delays and their components for which the total error term is minimised. We will discuss this error term and its possible contents in more detail below.

In general, we can define the delay, divided into components, as follows:

$$d_{s_o,s_d,k,n} = \sum_{(s_i,s_{i+1})\in E} \alpha_{s_i,s_{i+1},k,n} \times d^{wait}_{s_i,s_{i+1},k} + \sum_{(s_i,s_{i+1})\in E} \beta_{s_i,s_{i+1},k,n} \times d^{on-board}_{s_i,s_{i+1},k} + \sum_{(s_i,s_{i+1})\in E} \gamma_{s_i,s_{i+1},k,n} \times d^{trans}_{s_i,s_{i+1},k} + \epsilon_n \tag{2.1}$$

with s_o the origin station, s_d the destination station, k the time period, n $\in$ N the passenger trips, s_i, s_{i+1} a subset of E being the stations that the passenger traverses, α a constant that is 1 if $s_i = s_o$ and 0 otherwise, d^{wait} the initial waiting time delay, β a constant that is 1 if s_i, s_{i+1} is traversed by the passenger, $d^{on-board}$ the vehicle delay (i.e., the delay experienced during the ride), γ a constant that is 1 for a transfer station and 0 otherwise, d^{trans} the transfer delay and ϵ the error term. Furthermore, the vehicle delay d^{veh} for every vehicle v can be formulated as follows:

$$d^{veh}_{s_o,s_d,k,v} = \sum_{(s_i,s_{i+1})\in E} \beta_{s_i,s_{i+1},k,v} \times d^{on-board}_{s_i,s_{i+1},k} \tag{2.2}$$

with the notation as described above.

For an entire network, we can write these two equations as a system of equations, thus obtaining the matrix equation $C\mathbf{x} + \ = B$, where C contains ones and zeros (the α, β and γ of Equation 2.1 and Equation 2.2), **x** is a vector to be estimated, containing the delay components d^{wait}, $d^{on-board}$, and d^{trans}, B is a vector containing the experienced arrival delays per trip taken and ε contains the error terms for every passenger.

After obtaining the constrained linear least square solution for **x**, we can use the product of C and **x** to obtain the estimated total delays that every passenger encountered. We use these as the *arrival delays* in our further analysis.
We also create a matrix W, which has the same shape as matrix C, but in which only the α's (i.e., the constants for the origin station) are 1; thus, all β's and γ's are zero. By multiplying this matrix W again with **x**, we obtain the initial waiting time delay estimates that every passenger encountered. We use these as the *departure delays* in our further analysis.

Along with the origin and destination of the passenger, we use the obtained arrival and departure delays for further analyses, which will be discussed in section 2.3 and section 2.4.

2.2.2. Motivation for using aggregated estimates

Rather than using the experienced (i.e., non-estimated) passenger trip information, containing for every trip taken its tap-in and tap-out times, travel time, and delay, we use the aggregated delay component estimates, as described in the section above. The main reason for this choice is the fact that using aggregated component estimates enables us to also determine the departure delay, by merely looking at the initial waiting time delay component.This initial waiting time delay component is only available through the component estimation as described in the section above and cannot directly be determined from the experienced (i.e., non-estimated) arrival delay. To have an input to the refund scheme analysis that is as consistent as possible, we also use the (sum of) aggregated component estimates as our arrival delay.
The disadvantages of using these aggregated component estimates are the fact that it cannot accommodate for theoretical cases of passengers that have an arrival delay that is smaller than their departure delay, due to the fact that the delay components are always summed to obtain the arrival delay. It could theoretically happen that a vehicle would be delayed by 10 minutes (yielding a waiting time delay, i.e., a departure delay, of 10 minutes), but then makes up for the delay during the journey, yielding an arrival delay that is smaller than 10 minutes. This could theoretically be verified by comparing the vehicle data and examining the variability in travel time between stops, but we assume that the number of cases in which this actually happens is insignificant enough to neglect it. Furthermore, due to the absence of coupling a certain trip to a certain vehicle, it would not enable us to directly determine the trips for which the arrival delay was smaller than the departure delay.

A further point of attention is the fact that the delay component estimates could less accurately represent the actual delay that every passenger experienced. This can both be considered an advantage and a disadvantage, for the reasons discussed below.

Using the aforementioned delay component estimates minimises the influence that outliers in the actual passenger data might have on delays. These outliers might consist of trips by passengers spending more time at a station than can reasonably be expected from the walking times from train to exit, for instance, because of disabilities, trouble finding their smart card, or even deliberately waiting before checking out, in order to get a refund. If we had used merely the actual passenger trip information, there would be no way of telling these delays apart from the trip-related delays that can be estimated to have been encountered, whereas in the component estimation, the difference between the experienced delay and the estimated delay is stored in the error vector ε.
For the aforementioned limitation and reason, we use aggregated delay component estimates for our refund scheme analysis, which is described in more detail in section 2.4.

2.3. Link between delays and refunds

As stated in the introduction, we will examine a possible relation between the two main variables that can be expected to be linked in a passenger delay refund scheme, namely the delay encountered and the refunds given. To this end, we will perform a linear regression analysis, using the processed case study data as input. Next to this data, we need the fares that were refunded. As the fares from the study period (2017/2018) were not readily available, we use the current (2023) fares between all stations. We however assume this not to be an influence on the research we are carrying out, as the proportions of fares are assumed to roughly have remained the same. Furthermore, we use for our main analysis the estimated arrival delays per trip taken (i.e., the product of matrix A and vector $\mathbf{x}$, as described in subsection 2.2.1), and the subsequent refunds resulting from those delays when using the case study refund scheme as described in subsection 5.1.3. We choose time aggregations of one day, within which we sum the total delays that all passengers encountered, as well as the refunds given during the aggregation period. Subsequently, we divide these total delays and refunds given by the number of trips taken on that day. In this way, we obtain a two-dimensional plot of the average delay per trip (in a unit of time) on the x-axis and the average refunds per trip (either unitless or in a unit of money) on the y-axis, on which we can perform regression analyses to find the amount of (non)linearity present in this link.
Along with this regression analysis using the estimated arrival delays, we will also carry out the same procedure using the experienced arrival delays. The reason for this is that the estimations might not be available in all situations, which could make it useful to also examine the link between delays and refunds in this way. We will then examine the difference between using these component estimates and the actual passenger data input.
Regarding the refunds given, we both examine the link between the average delay per trip per day and the average refund paid per trip, as well as the average delay per trip and the number of refunds given per trip. For the former, we sum the amounts of refunds per day, and for the latter, we count the trips for each day that were eligible for a refund. The reason for this is that the linear effect of delays and refunds might be different when merely looking at the number of refunds paid (in a unit of money) rather than the number of refunds given (unitless).

2.4. Refund Scheme Evaluation

To evaluate the performance of refund schemes, we can establish Key Performance Indicators, or KPIs, which can help us quantify what is meant by ‘performance’. Furthermore, we need to define the refund schemes that we will test and consider the factors that need to be taken into account when designing them. As both of these are closely related to respectively the survey findings and the case study data, we will present the KPIs in section 4.2 and the refund schemes to be tested in section 5.2.

3

Survey: mapping the refund scheme landscape

In this chapter, we will present the survey, which helps us determine the state of the practice regarding refund schemes. First, the methodology for carrying out this survey will be presented in section 3.1. Subsequently, its results will be presented in a textual (section 3.2) and visual (section 3.3) manner.

3.1. Methodology

To carry out the survey, we first need to define its scope and its goal.

The scope of the survey is metros as well as metro-like systems such as lightrail or Stadtbahn, in cities of more than 500,000 inhabitants in Europe and North America. The reason for choosing this scope is the availability of data that will be used for the case study, which is a metro system in a city in the United States with a population of ± 700,000 people. In order to analyse refund schemes that are in cities and for systems with somewhat similar properties in terms of population, this scope has been chosen.
The goal of the survey is to determine the current state of the practice of passenger delay refund schemes, i.e., which refund schemes are currently in use, as well as (if applicable/retrievable) the history of these refund schemes, whilst keeping these two scope criteria in mind.

As already mentioned in the introduction, there was no scientific literature available regarding the state of the practice of passenger delay-based refund schemes. Hence, carrying out this survey was the mere source of information regarding these topics.
First, a list of cities was created with a population of over 500,000 and having a metro or metro-like system in use. Occasionally, cities with a population of less than 500,000 were also included, if the population of the greater urban area was over 500,000.
Information was searched for on the websites of the public transport operators responsible in the considered city. The operator of the metro network was found via a web search.
Initially, on the public transport operator websites, the 'customer service' section was searched, looking for information provided there about a possible refund scheme in use. If this section did not exist or did not provide any information, either the internal search function of the website was used, or Google was used to search the website. The search queries used in this case were different forms (and different translations, if applicable) of 'delay', 'reimbursement' and 'refund'. These search queries were used combined but also separately. Additionally, these same search queries, including either the name of the city or the name of the operator, were used in web searching for more information on the refund schemes (if present), for instance on newspaper websites.
The search queries in foreign languages were created by using Google Translate, using the aforementioned queries. Sometimes, the different translation possibilities that Google Translate provided were used. Information provided in Dutch, English, German, and French was read in the native language, whereas information in other languages was translated with Google Translate and/or DeepL.

Subsequently, the information that was present on the refund schemes in every city was condensed in an overview per city, which can be found in Appendix A. By reading through this condensed information, patterns of information were derived, which yielded section 3.2, containing the findings from the survey.
In order to discern spatial patterns among this information, map visualisations were made with Python. These can be found in section 3.3.

The elements found that could be used when designing a refund scheme have been used in section 4.1, in order to define the design aspects of refund schemes. The possible values that these elements can take are also taken from the survey.

3.2. Survey results

As already briefly mentioned in the previous section, the supply of information on the operator's chosen refund policy is generally very limited. With a few exceptions (e.g., Stockholm, London, Berlin), the information on the refund schemes that operators provide is usually relatively brief. However, the information that has been found is sufficient to conclude on the state of the practice, which had been the original goal of this survey, as well as to elaborate on some specific aspects of refund schemes.

The information that has been found on the websites of public transport operators, newspapers, etc., is summarised per city in Appendix A. A total of 57 cities with a metro(-like system) have been examined. Out of these, we found a refund scheme to exist for 30 cities.

Based on the information provided, a number of characteristics of refund schemes and the information provision can be discerned. The most important characteristics are the type of delay that is used as a criterion, the threshold for a refund scheme to get into action, and the amount refunded, be it the original fare or a fixed fare. Some additional characteristics include the possible refund of alternative transport taken, as well as the way in which the refund is reimbursed to the customer. These characteristics will be discussed in more detail in the sections below.

3.2.1. Type of delay measured

To issue a refund after a delay, it is first necessary to define the type of delay that will form the basis of the refund scheme. Within the state of the practice, a few types of delay can be identified: departure delay (or, related to this, a headway change), arrival delay (or an expected arrival delay) and – although this is strictly speaking not a delay form – a total service interruption.

Departure delay

Departure delay is the change to the scheduled departure time of the vehicle that the passenger affected by the delay planned to take, leading to a late arrival, or even missing transfers. Examples of refund schemes based on departure delay are the state-wide refund scheme of Nordrhein-Westfalen (Germany), where alternative transport can be taken (and refunded) if a planned service has not departed 20 minutes after the scheduled time of departure.
A variation on the departure delay is a change in headway, which is used by the Madrid Metro for determining the refund eligibility; for instance: if the metro headways exceed 15 minutes, whereas normal service envisions headways < 7.5 minutes, the refund scheme is put into action.
Out of the 30 cities with a refund scheme, 15 cities use this delay type.

Arrival delay

As a second form of delay, we can identify the refund schemes that are based on arrival delay, i.e., the change to the scheduled arrival time of the vehicle that the passenger affected by the delay was planning to take. This arrival delay can either fully be caused by the departure delay (possibly minus some recovery time), but it could also be caused by a delay encountered whilst travelling on a vehicle, or by a missed transfer if the journey includes one. Arrival delay-based refund schemes can for instance be found in London, where the fare is reimbursed for a 15-minute, or later, arrival at the destination, or The Hague, where a fixed amount of € 3.- is refunded for any arrival delay exceeding 30 minutes. Out of the 30 cities with a refund scheme, 9 cities use this delay type.
As a variant of the arrival delay, refund schemes based on the expected arrival delay can be identified,

which are for instance used in Stuttgart (DE). In this particular case, alternative transport can be taken if the destination can reasonably be expected to be reached with a delay exceeding 20 minutes. Out of the 30 cities with a refund scheme, 4 cities use this delay type.

Service interruption
A last form of delay is a total interruption of service, although we could question whether this could classify as a delay. However, since the impacts for passengers are comparable (it interferes with them reaching their destination at the promised time), we do include the refund schemes that merely refund when service interruptions occur, like the Charleroi pre-metro which refunds a part of a seasonal ticket with a service interruption taking more than two hours.

A few points of attention are meaningful to discuss here. Firstly, refund schemes that are based on the (actual, rather than expected) arrival delay make an implicit assumption: that the trip taken has been able to be completed. However, many refund schemes of this form have no policy in place in case of a destination that is completely unable to be reached, as could be the case for large-scale service interruptions. In contrast, departure delay-based refund schemes also have the possibility to issue a refund if the destination is unable to be reached, for instance for cases of departure delay being so large that the last transfer possibility of the day is not feasible anymore. Also, expected arrival delay-based refund schemes have this possibility, as discussed for Stuttgart above.
Consequently, the link between the type of refunded delay and a possible refunding of alternative transport is also relevant to discuss. We will return to this link in more detail below.

3.2.2. Delay threshold

The delay threshold, as we define and use it here, is the minimum delay from which a refund is issued. Generally, the delay threshold has been found to be around 15 or 20 minutes, although occasionally smaller values occur, such as an increase in headway of 7.5 minutes (Madrid). The largest threshold found was 120 minutes for the Charleroi pre-metro, in case of service interruptions that exceed two hours. It should be noted, however, that this large threshold would merely make sense with a service interruption; a 120-minute arrival or departure delay threshold could arguably be less useful.

3.2.3. Type of refund given

Regarding the type of refund given, we can discern four different refund types: monetary refund, fare reimbursement, ‘voucher’ refunds, and alternative transport refunded.

Monetary refund
Arguably, the simplest form of refund is a fixed monetary amount. This refund is for instance used in The Hague and Turin, where in both cases a refund of €3 is paid, either for a >30-minute delay (The Hague) or a >60-minute delay (Turin), regardless of the original fare paid for the journey or the delay encountered. The latter could obviously also be varied (for instance by providing several tiers of fixed monetary refund depending on the delay magnitude), however, this has not been observed for any of the studied cities.

Fare reimbursement
Another, related, refund type is the restitution of (a part of) the original paid fare for the journey. This is by far the most common type of refund issued. One could state that this is also one of the fairest bases for issuing a refund, as it could be considered to partially compensate the disutility of the delay during the journey, by minimising another disutility encountered during the journey (the ticket price). If multiple journeys were paid for in advance, for instance when the affected passenger is using a seasonal ticket or subscription, a part of the subscription can be refunded instead. Most refund schemes that use this form account for both of these situations, although there are exceptions, such as Madrid (single tickets refunded, but no seasonal tickets), or Charleroi (a fraction of the seasonal ticket refunded, but no single tickets). However, most cities using this refund type have refunds for both of these ticket forms, such as Hannover, where the original fee is refunded for single-use tickets and a fixed amount of € 5.- for subscription holders.

Voucher refunds

As a third form of refund, we can identify a “voucher-like” refund, where, regardless of the original fare, free tickets are granted. Depending on the tariff system of the operator considered, this can be for a trip of a certain distance or a trip of a certain time. One of the most elaborate refund schemes using this refund form can be found with the Rotterdam Metro, where no less than three situations are discerned for which different travel vouchers are issued. Another example of this refund form can be found in Berlin.

Finally, we can discern refund schemes which issue a refund based on alternative transport taken (which we will discuss in more detail in the next section). Most often, the maximum refund issued in these cases is capped at a certain amount.

3.2.4. Additional characteristics

Next to these main characteristics, there are also a number of additional characteristics found. These will be described in the sections below.

Alternative transport refunded

With some refund schemes, the possibility to use alternative transport is included. This may be a viable option if it can reasonably be assumed that the destination will be unable to be reached by using the intended mode of transport. Refund schemes that are based on arrival delay (see above) can be expected to have no alternative transport refund in place (as the journey has then already been completed). However, some refund schemes using departure delay or expected arrival delay as a metric enable taking alternative transport, such as the ones used in Copenhagen, or Stuttgart, respectively. When a refund scheme uses service disruptions as a criterion, alternative transport is much more common to be accounted for, which could be explained by the fact that service disruptions can greatly increase the number of journeys that are not feasible by the original mode(s) of transport anymore.

Manual/automatic reimbursement

With the exception of London and Washington DC, all refund schemes require manual action for a refund to be issued. Some of this manual action can occur online, for instance, an online form that can be filled out on the website of the operator. In other cases, operators are requiring paper forms to be filled out. Furthermore, some reimbursements occur online (for instance by bank transfer or electronic tickets) and some occur in person, for instance by issuing the refunded amount in cash.
With refund schemes requiring manual action, it can be argued that good findability is vital for the refund scheme to be effective. However, this is far from always being the case, as we will discuss in more detail below.

Individual trip delay or generalised punctuality

All refund schemes found are individual trip-oriented, meaning that the individual passenger making a delayed trip is personally eligible for a refund. However, there is one notable exception, being the refund scheme used in the urban area of Paris, where the punctuality (with a threshold of 80%) on metro and RER lines is taken as a basis for refunding passengers living close to the affected line and being in possession of a seasonal ticket. The 80% punctuality is calculated as: more than one out of five passengers arrive at their destination with a >5-minute delay. In theory, this approach could even lead to situations where passengers are refunded that did not actually experience a delay but do happen to live around the affected line.

Findability

Although findability is strictly speaking not a characteristic of a refund scheme, its functioning can be assumed to be affected by it. By comparing the effort that it took to find the information on the refund schemes, we can safely state that there is a large variance in the findability of every refund scheme. For instance, some refund schemes are very easily findable and even advertised on the main page of the website of the operator, as is, for instance, the case for Copenhagen. Other refund schemes can be found by going to the ‘customer service’ section of the operator, which could still be considered to be easily findable. However, some other refund schemes are hardly mentioned on the website of the

public transport operator or are only mentioned in the general terms and conditions. This could arguably lead to fewer people being familiar with the refund scheme, which might lower its effectiveness.
A clear example where findability might play a major role is in Italy, where according to several sources, a nationwide refund scheme is in place. One could expect this information to be reinstated on the website of the public transport operator of the considered city. However, not a single public transport operator in Italy has this information on its website. Hence, the frequency of use by the public of this refund scheme is unknown, let alone the 'success rate', i.e., how many refunds are actually granted, even when the affected passenger were to meet all eligibility criteria.

3.3. Overview of refund schemes

To see the information that has been found in the survey at a glance, several map visualisations have been made, as well as a table.
The following visualisations were created with Python, the folium package (using Leaflet) and a .csv file created, which has also been used as a basis for Table 3.1 as to be found further below. In Figure 3.1 and Figure 3.2, it is shown whether a refund scheme is in use for the indicated city. A red marker indicates no refund scheme is in use for the indicated city, a green marker indicates that there is a refund scheme in use. A separate visualisation for North America has not been created, due to the fact that merely one city (Washington DC) had a refund scheme in use.

Figure 3.1: Overview of refund scheme in use/not in use per city. Green markers indicate a refund scheme is in use, red markers indicate no refund scheme is in use

Figure 3.2: Overview of refund scheme in use/not in use per city: zoom on West Germany/Netherlands/Flanders. Green markers indicate a refund scheme is in use, red markers indicate no refund scheme is in use

From these figures, we can make a few observations. The most striking observation from Figure 3.1 and Figure 3.2 is the fact that for most of the countries observed, either all or no cities with a metro(-like system) have a refund scheme in use. For instance, in Germany, most cities have an independent refund scheme in use. In the case of Italy, there is a nation-wide refund scheme in use.
Furthermore, very roughly speaking, refund schemes seem to be more common in the north-western half of Europe than the south-eastern half.
Next to the map visualisations, the following information of the preceding section is summarised in Table 3.1, albeit only including the cities with a refund scheme in use:

- **Co**untry
- **Ci**ty
- **D**elay **T**hreshold (minutes)
- **M**anual/**A**utomatic reimbursement
- Delay Form: Departure/Arrival/Expected arrival delay/Generalised arrival delay used as criterion
- Refund Form: Monetary / (part of) Original Fare / Voucher Ticket / Alternative Transport
- **P**roof of **A**lternative transport needed? (Yes, No)
- Further Remarks

Co	Ci	DT	M/A	Delay Form	Refund Form	PA	Further Remarks
BE	Charleroi	120	Manual	Departure	Original Fare	No	Only for subscription holders
DK	Copenhagen	30	Manual	Departure	Alternative Transport	Yes	
FR	Paris	0	Manual	Generalised Arrival	Original Fare	No	See description
DE	Berlin	20	Manual	Arrival	Voucher Ticket/Alternative Transport	No	Alternative transport 23:00-05:00
DE	Hamburg	20	Manual	Arrival	Original Fare	No	
DE	Munich	20	Manual	Arrival	Monetary/ Alternative Transport	No	Alternative transport in case last transfer miss
DE	Cologne	20	Manual	Departure	Alternative Transport	Yes	
DE	Düsseldorf	20	Manual	Departure	Alternative Transport	Yes	
DE	Dortmund	20	Manual	Departure	Alternative Transport	Yes	
DE	Essen	20	Manual	Departure	Alternative Transport	Yes	
DE	Duisburg	20	Manual	Departure	Alternative Transport	Yes	
DE	Frankfurt a.M.	10	Manual	Arrival	Original Fare	No	
DE	Stuttgart	20	Manual	Expected Arrival	Alternative Transport	Yes	
DE	Hannover	20	Manual	Expected Arrival	Original Fare / Alternative Transport/Monetary	Yes	Alternative transport for >60 minute delay or 23:00-05:00
DE	Nürnberg	15	Manual	Arrival	Monetary/ Alternative Transport	No	Alternative transport after 20:00 or weekend
IT	Rome	30	Manual	Departure	Original Fare	No	
IT	Milan	30	Manual	Departure	Original Fare	No	
IT	Naples	30	Manual	Departure	Original Fare	No	
IT	Turin	60	Manual	Departure	Monetary	No	
IT	Genoa	30	Manual	Departure	Original Fare	No	
NL	Amsterdam	60	Manual	Departure	Alternative Transport	Yes	
NL	Rotterdam	30	Manual	Departure	Voucher Ticket/Alternative Transport	No	Alternative transport for delays >60 min
NL	The Hague	30	Manual	Arrival	Monetary	No	
NO	Oslo	20	Manual	Departure	Alternative Transport	Yes	Presumably departure delay, not specified

ES	Madrid	7.5	Manual	Departure	Original Fare	No	
SE	Stockholm	20	Manual	Expected Arrival	Alternative Transport	Yes	
GB	London	15	Automatic	Arrival	Original Fare	No	
GB	Newcastle	15	Manual	Arrival or Departure	Original Fare	No	
US	Washington D.C.	15	Automatic	Arrival	Original Fare	No	Only in rush hour

Table 3.1: Overview of refund schemes per city that has a refund scheme in use

Based on the categorisation performed in this survey, this table can serve as a start for establishing the predominating factors that differ between refund schemes. We will use these in the next chapter to create a conceptual framework showing the relations between these factors, which we will eventually use to create an overview of design aspects for refund schemes.

4

Designing and assessing refund schemes

4.1. Design aspects of refund schemes

In the preceding section, we have discussed the elements that should be considered for designing a delay refund scheme. The links between the elements that have been found in the state of the practice are shown in the conceptual framework in Figure 4.1. In this conceptual framework, the **properties** are elements that are part of a refund scheme, upon which a public transport operator can actively exert influence. The **variables** are the elements that determine the eventual refund given but are not determined by the public transport operator, at least not considering the refund scheme. Finally, the **outputs** show the end product that the user receives.

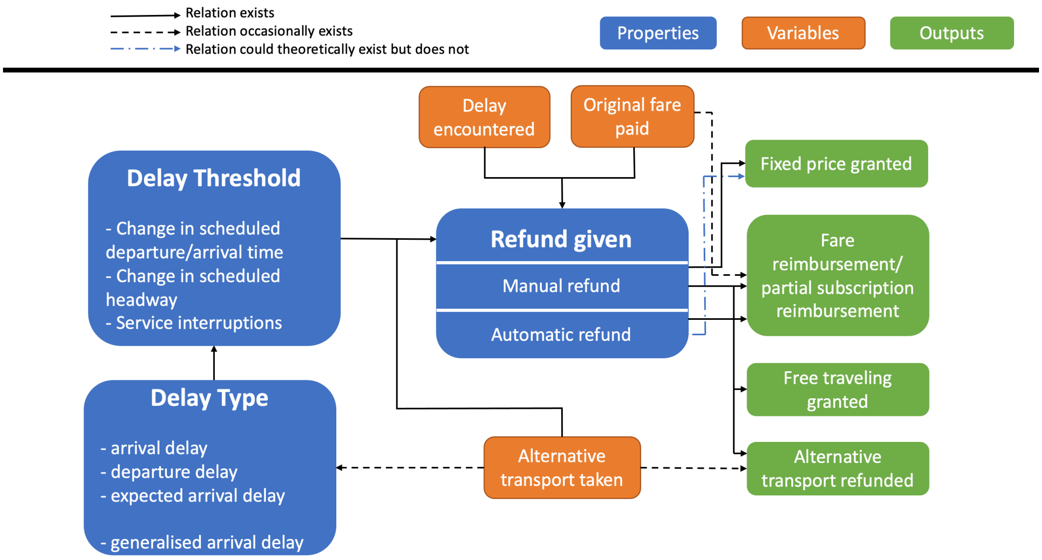

Figure 4.1: Conceptual framework for designing a delay refund scheme

As *delay types*, we have arrival delay (i.e., a deviation from the scheduled arrival time), departure delay (i.e., a deviation from the scheduled departure time), expected arrival delay (i.e., a deviation from the expected scheduled arrival time) and generalised arrival delay (i.e., a deviation in punctuality on a certain line or route). The expected arrival delay might be relevant in cases where it has not been possible to reach the originally planned destination. The generalised arrival delay is not linked to punctuality (i.e, a deviation in scheduled arrival time) on an individual level, but averaged on a line or route level over a longer period of time.

The delay type is linked to the *delay threshold*, which includes a change in the scheduled departure or arrival time, a change in scheduled headways between services, and service interruptions.
The delay threshold is used as an input to the *refund given*, alongside the *delay encountered*, the *original fare paid*, and possibly the *alternative transport taken*. The latter is considered to be also linked to the delay type because it can be expected to only use alternative transport in cases where the destination has not been reached. This is as such only possible for refund schemes that use either departure delay or expected arrival delay.
The refund given can be either manual (i.e., action from the passenger is still required before they receive a refund) or automatic (i.e., the refund is automatically reimbursed to the passenger, for instance through their smart card). For manual refunds, either a *fixed price* regardless of the fare paid can be granted, the *original fare/partial subscription* can be reimbursed, *free travelling* (for instance by means of a voucher) can be granted or *alternative transport* can be refunded. For automatic refunds, the original fare or part of a subscription can be reimbursed, or a fixed price can be granted, although the latter has not been observed for any of the studied cities.

The elements that can be used as design aspects are summarised in Table 4.1, showing these elements, as well as the possible values that they can take. These design aspects could be used by public transport operators when they establish a refund scheme. Therefore, we will use these design aspects to define our refund schemes for the case study in section 5.2.

Criterium	**Possible values**
Delay type	Departure, Arrival, Expected Arrival
Delay threshold	7.5-60 minutes; avg. 15-30 minutes
Refund type	Monetary, Original Fare, Voucher, Alternative Transport
Alternative transport included	Yes, No
Punctuality type	Individual, Generalised

Table 4.1: Design aspects of refund schemes

In the preceding table, a number of elements found in the survey and/or the conceptual framework from Figure 4.1 are not included. We will briefly discuss why these elements are not included.
Firstly, we do not include service interruption as a delay type, as this is arguably not a delay type, but a different event, although some refund schemes do include a refund for a service interruption. We also do not include manual vs. automatic reimbursement as a design criterion, as this does not affect the link between the delay encountered and the refund given. Automatic reimbursement can be expected to increase the 'success rate', i.e., the share of refunds that are actually granted amongst trips that were eligible for a refund, but we consider this to not be related to the refund scheme itself.

4.2. Assessment indicators of refund schemes

To quantify how a certain refund scheme performs, we define a number of key performance indicators, also called KPIs, which enable us to focus on certain aspects of the performance of a refund scheme. There are two major advantages to using KPIs. Firstly, they make clearer what is meant by 'performance', and secondly, they facilitate comparing the performance of different refund schemes. We will carry out the latter in section 6.3.

4.2.1. Number of refunds per trip given

This KPI is the ratio between the total number of trips taken and the number of trips that have been refunded. One could argue that this KPI would be less relevant to clarify the 'performance' of a refund scheme, as described above because no information is included on the monetary side of the refund scheme. However, it can be useful in order to compare different (parameters of) refund schemes.

We can mathematically formulate this KPI as follows:

$$RPT = \frac{\sum_N f_{r,n}}{N} \tag{4.1}$$

where RPT stands for **R**efunds **P**er **T**rip, N is the total number of trips taken, n $\in$ 1, … , N , and f_r is a dummy variable taking the value 1 if a trip is eligible for a refund, and 0 otherwise.

4.2.2. Delay Ratio

This KPI mainly compares the effect that the distribution of delays has on the refunds issued, when using different delay thresholds. To this end, both the average delay of all trips and the average delay of all refunded trips are calculated. These are subsequently divided by each other. The differences in outcome can be explained by the fact that the amounts of refunds issued in a system can both depend on the delays experienced during the trips, but also on the way in which the delays are distributed amongst those trips. For example, in a system having a refund scheme with a 10-minute delay threshold, the average delay in the system could be 5 minutes, but depending on the spread of the delays, either only a few trips could be refunded (with delays that are far above the refund threshold) or many trips could be refunded (with delays that are just above the refund threshold). This KPI shows the spread of the delays against the average delay in the system.

We can mathematically formulate this KPI as follows:

$$DR = \frac{\frac{\sum_N f_{r,n} \cdot d_{r,n}}{\sum_N f_{r,n}}}{\frac{\sum_N d_{r,n}}{N}} \tag{4.2}$$

where DR stands for **D**elay **R**atio, d_r the delay (i.e., the deviation from the expected travel time) encountered on trip r, and N and f_r as described above.

4.2.3. Ticket revenues to refunds paid ratio

For this KPI, only the refunded trips are considered. The KPI compares the original fares paid for all trips to the refunds that are given, by calculating the percentage of ticket sales that is paid back in refunds.

We can mathematically formulate this KPI as follows:

$$RTR = \frac{\sum_N m_{r,n} \cdot f_{r,n}}{\sum_N p_{r,n}} \tag{4.3}$$

where RTR stands for **R**evenue **T**o **R**efund, m_r the refund received for the trip, p_r the original fare paid for the journey, and f_r as described above.

4.2.4. Time loss compensation share

This KPI considers the total passenger time losses experienced over a certain period of time (i.e., a day or a month) and appends a certain Value of Time to it, to determine the monetary losses that all delays have generated. Subsequently, these monetary losses according to the time losses are compared to the refunds given by the examined refund scheme, to determine the 'accuracy' of the refund scheme when looking at the time losses compensation. For this KPI, all delays in the denominator are summed, i.e., a 1-minute delay is also considered a delay.

We can mathematically formulate this KPI as follows:

$$TLCS = \frac{\sum_N m_{r,n} \cdot f_{r,n}}{\sum_N VoT \cdot d_{r,n}} \tag{4.4}$$

where TLC stands for **T**ime **L**oss **C**ompensation **S**hare, VoT the Value of Time, d_r the delay encountered on trip r and m_r and f_r as described above.

5

Case study introduction and inputs

5.1. Introduction to WMATA network and data

The case study network that we will be examining in more detail is the metro network of Washington D.C., in the United States, operated by the Washington Metro Area Transport Authority, or WMATA. The network, data, its refund scheme and its Value of Time (VoT) will be discussed in more detail in the sections to follow.

5.1.1. Case study network

At the time of data collection, the network comprised 6 lines, indicated by colours, serving a total of 91 stations (of which 9 transfer stations), and a total of 193 links connecting them. A system map showing the lines, as well as the denotations of the stations in the system, is shown in Figure 5.1. As can be seen from the figure, the network structure is predominantly radial. The stations with the highest ridership are Union Station, which serves the city's main train station (but interestingly is merely served by one metro line, being the Red Line), as well as Metro Center. The high ridership of the latter might partially be explained by the fact that it is a transfer station between the Red Line (serving Union Station) and three other metro lines.

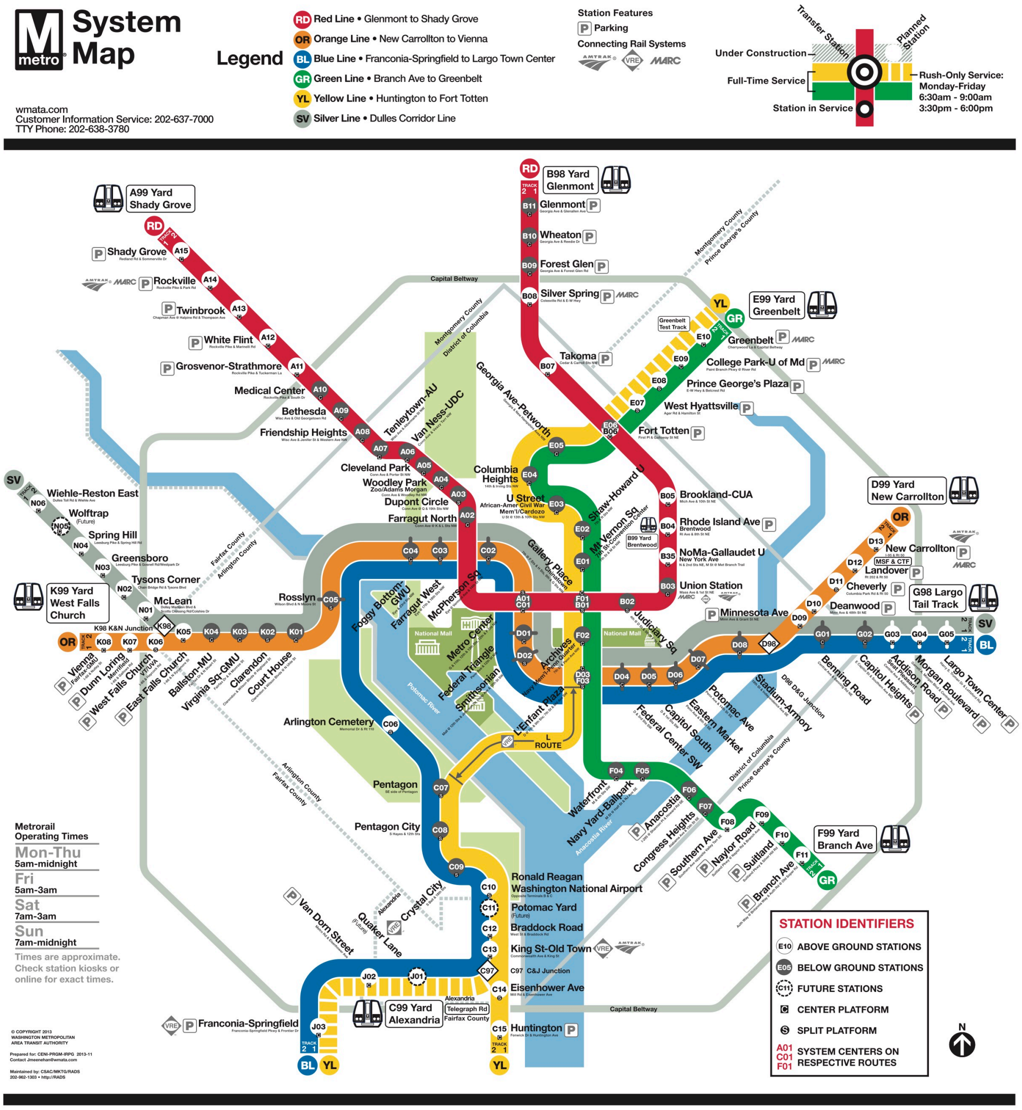

Figure 5.1: WMATA network system map

5.1.2. Case study data

For this network, we have approximately one year of data available, from the 19th of August 2017 until the 31st of August 2018. The data available that has actually been used in our subsequent analysis comprises:

- passenger movement data, which contains (amongst other, less relevant fields) of every journey taken by a passenger the start location, end location, vehicle type (bus or metro), as well as movement types (tap-in, tap-out, gated transfer or ungated transfer) with corresponding time stamps.
- rail movement data, which contains (amongst other, less relevant fields) for every trip that a train has taken the stations that it has passed, as well as the time stamps at which it arrived, opened and closed its doors, and departed.
- schedule data, which contains every origin/destination pair (i.e., start and end station), as well as the minimum and maximum scheduled travel time between these two stations. This maximum scheduled time can consist of 1) the walking time from the check-in location to platform, and v.v., 2) the maximum vehicle travel time, 3) the maximum headway between two vehicles at that particular time of day.

- disruption logs, which include the incident start time, the location (i.e., the station and line), the cause and category of the disruption, and the minutes of delay that the disruption caused.
- trip ID's, which are an unique ID given to the trip.

Additionally, we use the processed data with the methodology as found in section 2.2.

5.1.3. Case study refund scheme

A refund scheme applies to the entire metro network at all moments. For this refund scheme, the delay encountered for every trip is calculated by comparing the experienced travel time (from tap-in to tap-out time) to the maximum time that travelling between that origin-destination (OD) pair can be expected to take, as described in subsection 2.2.1. The delay threshold for granting a refund was 10 minutes of arrival delay at the moment that the data was retrieved. The refund given is the original fare paid for the journey, reimbursed automatically onto the smart card of the passenger.

5.1.4. Case study Value of Time (VoT)

For the Value of Time, which we need in order to make calculations on the fourth key performance indicator (KPI) as defined in section 4.2, we use in this case study a value as found in Yap and Cats (2023), stemming from empirical findings from Washington DC: one dollar equals a disutility of 2.58 minutes of travel time. For 60 minutes, i.e., one hour, this yields a Value of Time of $23.25, which is the value that we will use.

5.2. Refund schemes to be tested in case study

The refund schemes that we will use for the case study will use the original WMATA refund scheme as a basis, as described in subsection 5.1.3. We take (the parameters of) this refund scheme as a basis for a parameter sensitivity analysis, varying one parameter at a time. These parameters have been taken from the design aspects of refund schemes, as described in Section 4. In this case, as parameters to vary, we use the delay type measured (either arrival or departure), the delay threshold (10 or 20 minutes), the refund type (original fare or monetary) and the form of punctuality measured (of an individual trip, or generalised over OD-pairs). As input data, we use each trip taken during the study period with its delay component estimates as defined in subsection 2.2.1:

- the departure delay (i.e., the product of matrix W and vector **x**, as described in subsection 2.2.1),
- the arrival delay (i.e., the product of matrix A and vector **x**, as described in subsection 2.2.1)
- the generalised arrival delay (i.e., the average arrival delay over a certain time period).

Additionally, we use the fare that was paid for every trip taken. We evaluate the results that these refund schemes yield when tested on the case study data according to the KPIs established in section 4.2. We furthermore assume that the reimbursement is automatic for all refund schemes, and as such, that 100% of the trips that meet the eligibility criteria actually get refunded, i.e., we do not account for possible failed declarations of a refund.

5.2.1. Parameters to include

As alternative transport is not relevant for the WMATA case study, the influence of this parameter will not be examined. Determining the possible alternative transport modes and their respective fares for the WMATA delays observed would go beyond the scope of this research, as the WMATA data set merely contains trips that actually have been finished. For the same reason, an expected arrival delay threshold is irrelevant for this case study. Hence, we merely consider arrival and departure delay. Also, the inclusion of travel vouchers is considered not to be relevant for this case study. This could have been relevant if, for instance, a stated preference experiment would be held among refund receivers, but also this goes beyond the scope of this research. Hence, the mere variance of the refund type will be either a monetary refund or the original fare.

5.2.2. Overview of to be tested refund schemes

Table 5.1 shows the refund schemes that will be tested in the case study. In the next section, we will evaluate these refund schemes according to the KPIs defined in section 4.2.

Name	Delay type	Delay threshold	Refund type
A/10/O	Arrival	10 minutes	Original fare
A/15/O	Arrival	15 minutes	Original fare
A/20/O	Arrival	20 minutes	Original fare
D/10/O	Departure	10 minutes	Original fare
D/15/O	Departure	15 minutes	Original fare
D/20/O	Departure	20 minutes	Original fare
A/10/F	Arrival	10 minutes	Flat fare
A/15/F	Arrival	15 minutes	Flat fare
A/20/F	Arrival	20 minutes	Flat fare
D/10/F	Departure	10 minutes	Flat fare
D/15/F	Departure	15 minutes	Flat fare
D/20/F	Departure	20 minutes	Flat fare
G/80%/S	'Generalised' arrival	80% punctuality	Part of seasonal ticket
G/85%/S	'Generalised' arrival	85% punctuality	Part of seasonal ticket
G/90%/S	'Generalised' arrival	90% punctuality	Part of seasonal ticket

Table 5.1: Refund schemes for case study

The column 'Delay type' indicates the form of delay that will be used for the respective refund scheme. We use the arrival and departure delay as defined in subsection 2.2.1. The 'generalised' arrival delay type is explained in further detail in subsection 5.2.4. Furthermore, the column 'Delay threshold' indicates the minimal delay above which a trip is eligible for a refund, and the column 'Refund type' indicates the type of refund that is given to the trip when it encountered a delay above the threshold.

5.2.3. Application of refund schemes with flat fare refund

In order to calculate the refunds given to passengers under a "flat fare amount'-refund scheme (7-12 in the table above), we average the fare over all trips taken during the study period. This is $ 3.08. In order to have a more realistic figure which could theoretically have been presented to travelers, we round this to $ 3.00, which will be the fixed amount that will be refunded for a trip with a delay above the delay threshold.

5.2.4. Application of refund schemes with generalised arrival delay

We apply the three refund schemes that use the 'generalised' arrival delay (13-15 in the table below) as follows.
First, we establish a time frame in which punctuality drops below a certain percentage. In line with the Paris area refund scheme on which the two case study refund schemes are based, we use an arrival delay threshold of 5 minutes for this. However, we use the punctuality on OD-pairs rather than lines, due to the large amount of bundling of metro lines in the WMATA network. This bundling would render it impossible to tell which line had punctuality that dropped below 80 per cent, as there is no information on which line the trip was made. We calculate the punctuality by determining the total number of trips taken during the study period with a >5-minute delay. This could create a bias towards the rush hours as the ridership during these hours is higher, but because the punctuality of vehicles (which would not have this bias) is not registered in the available data, we use trip-based punctuality. Furthermore, we make the following assumptions:

- The amount of rail trips taken on passes was nearly 10% in Q1 of 2020 (WMATA (2023)). We assume 10%.
- The price of the seasonal ticket (per month) equals 36 times the price of a single trip – this has been lowered to 32 times since 2022 (Mirzai (2023)), but we still assume 36 times as being more representative for the study period
- The average amount of trips per day taken on a seasonal ticket is 2.2 (Jelenius and Cebecauer (2020))

Thus, the number of refunds granted can be summarised using the following formula:

$$RG = STS \times STM \times TPS \times \sum_{OD} p_{od} \cdot e_{od} \quad \forall od \in OD \tag{5.1}$$

with:

- RG standing for Refunds Granted
- STS standing for Season Ticket Share (taken as 0.1 for our case study)
- STM standing for Season Ticket Multiplier, i.e., the amount of single trips that a seasonal ticket costs per month (taken as 36 for our case study)
- TPS standing for Trips per Seasonal ticket, for which we use $2.2^{-1} = 0.454$
- p_{OD} = fare for OD
- e_{OD} dummy (taking the value 1 if punctuality on OD is below the threshold, 0 otherwise)
- $od \in OD$ the set of OD's

5.3. Delays per trip: descriptive statistics of processed data

In this section, we will offer some descriptive statistics about the data that has been obtained from the WMATA dataset provided. The study period lasted from the 19th of August, 2017, until the 31st of August, 2018. Due to some unprocessable days, the total number of days of data obtained is 361, which yields almost a year of data. During these 361 days, a total of 157,355,833 trips has been taken. After processing the data in the way described in subsection 2.2.1, we obtain for every trip taken both the departure delay (i.e., the initial waiting time delay component from Equation 2.1) and the arrival delay (i.e., the sum of all components from Equation 2.1). The histogram in Figure 5.2, shows the distribution of the departure delays of the entire study period and the histogram in Figure 5.3 shows the same for the arrival delay distribution. Due to the distribution of the delays, logarithmic y-axes have been used. Furthermore, in Table 5.2, the counts of these delays are shown.

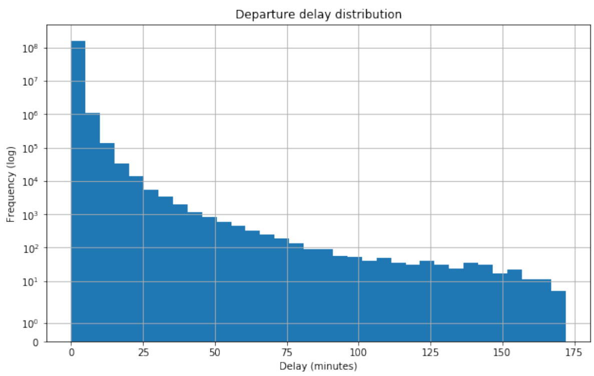

Figure 5.2: Histogram for the departure delay distribution during the study period

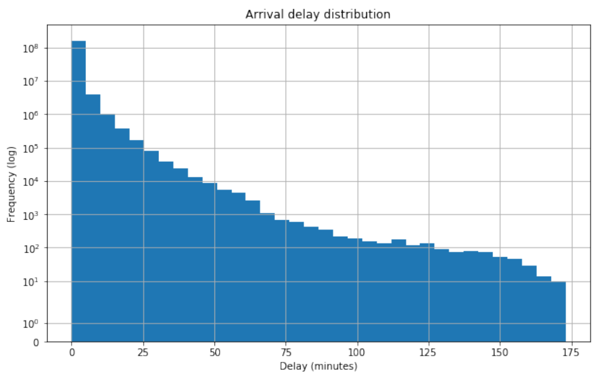

Figure 5.3: Histogram for the arrival delay distribution during the study period

Delay (min)	Departure delay #trips (%)		Arrival delay #trips (%)	
<1	128,680,750	(81.8 %)	94,994,850	(60.4 %)
1-5	26,709,424	(17.0 %)	54,929,729	(34.9 %)
5-10	1,703,153	(1.08 %)	5,297,186	(3.37 %)
10-30	251,756	(0.16 %)	2,021,668	(1.28 %)
30-60	9,087	(0.006 %)	103,456	(0.066 %)
>60	1,663	(0.001 %)	8,944	(0.006 %)

Table 5.2: Counts for the departure and arrival delay distribution during the study period

We can make a few conclusions based on these observations. By looking at the histograms, the distribution of departure delays seems to have less kurtosis, i.e., large departure delays seem to be less often occurring if compared to the distribution of arrival delays. This can partially be explained by the summative nature that was used for the departure and arrival delay estimate calculations: a trip will in this calculation method always have a smaller departure delay than its arrival delay. We will discuss the validity of this assumption briefly in chapter 7.

5.4. Estimated vs. experienced delays

In the preceding section, we have looked at the (descriptive statistics of) the arrival and departure delays that can be estimated by the methodology described in section 2.2. However, we will also analyse the link between delays and refunds in section 6.1 using the experienced arrival delays, to see to which extent they differ. Furthermore, it can be considered useful to examine the possible erroneous or fraudulent behaviour that passengers show, as described in subsection 2.2.2. Therefore, we will now take a look at the way in which the estimated and experienced delays differ. To start with, Figure 5.4 shows the histogram for the experienced arrival delay distribution. To make comparisons clearer, the contours of the experienced arrival delay histogram and the estimated arrival delay histogram are shown in Figure 5.5.

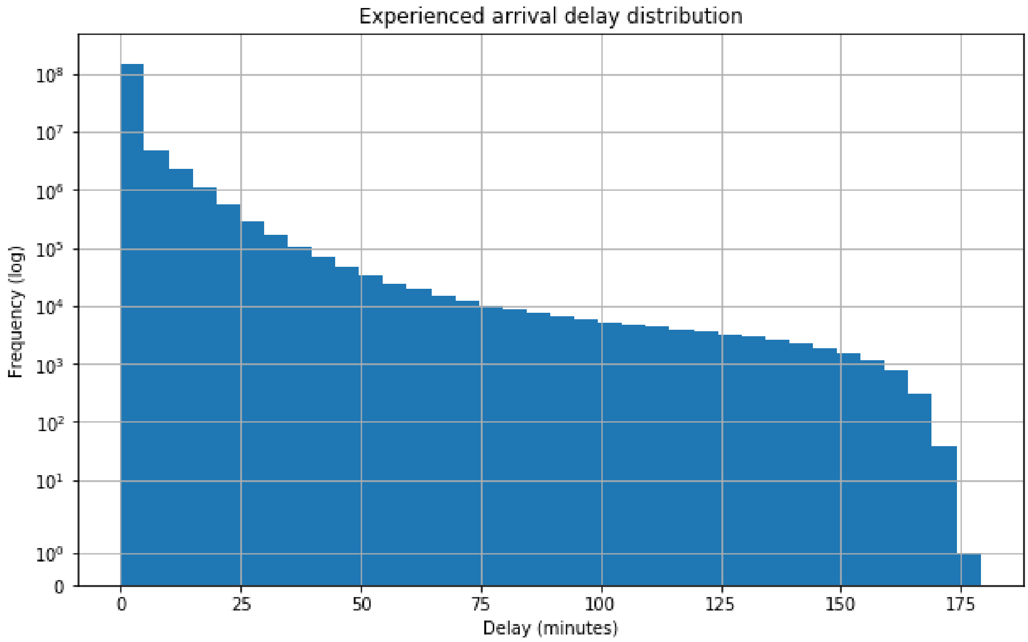

Figure 5.4: Histogram for the experienced arrival delay distribution during the study period

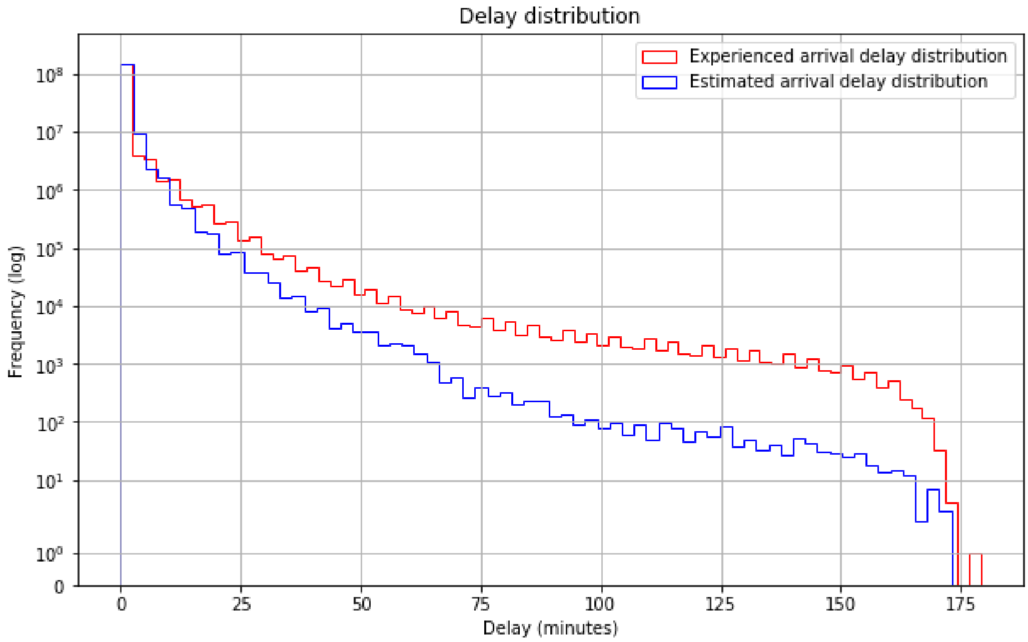

Figure 5.5: Histogram for the experienced and estimated arrival delay distribution during the study period

As can be seen when comparing these two histograms, the distribution of the experienced and calculated arrival delays is rather different: the share of large delays (i.e., delays exceeding 30 minutes) seems to be considerably higher for the experienced arrival delays, compared to the estimated arrival delays. However, the share of small delays is lower for the experienced arrival delays. In other words, the estimations seem to overrepresent shorter delays, but underrepresent longer delays. Several reasons can be thought of as to why these two deviate. Firstly, the individual behaviour of passengers can vary, due to deliberate behaviour, such as passengers getting a coffee or meeting a person at a station. The behaviour could also vary due to force majeure (such as disabled passengers using the metro, crowding which increases walking times to the check-out gates, or passengers losing their smart card). Both of these would lead to a larger experienced delay than the estimations would yield given the delay occurring during the waiting for the vehicle, possibly transferring to another vehicle, and the on-board delay. It can also be the result of the time aggregations necessary for executing the estimate calculations (i.e., trips 'entering' the system at a different moment than the delay occurring).

We could however also imagine a different form of deliberate behaviour occurring. This behaviour could be practised by passengers who would deliberately expedite their check-out time in order to receive a refund, by methods such as deliberately waiting for the next service to depart, or waiting for 10 minutes at the check-out gate in order to ensure that their trip will be registered as delayed, and as such, fully refunded. We cannot estimate the share of passengers that would be exerting this type of behaviour. However, zooming in on the experienced arrival delay distribution around the delay threshold maintained by the WMATA (10 minutes) could give us a rough estimation. To this end, in Figure 5.6, a zoom on the experienced arrival delay distribution as was seen in Figure 5.4 is shown.

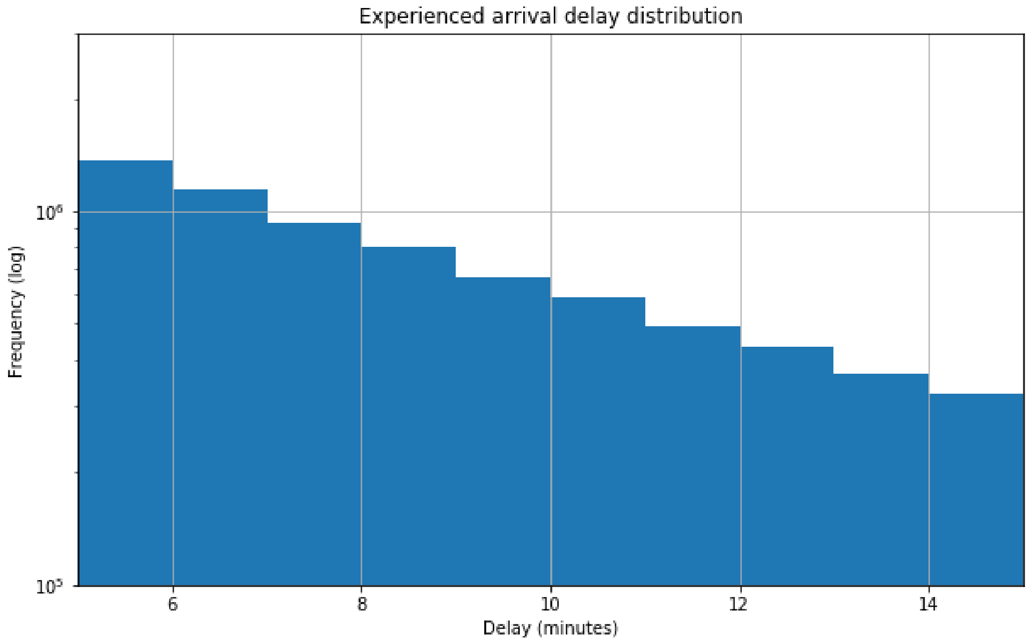

Figure 5.6: Histogram for the experienced arrival delay distribution during the study period, zoom on 5-15 minutes

Based on this figure, no significant 'jump' in delays from 9 to 10 minutes can be seen. In other words, the 'decay' of delays is not deviating to a large extent between 9 and 10, or even 10 to 11 minutes. Therefore, we can conclude that, although there might still be a share of passengers exerting behaviour in order to make their delay deliberately larger in order to receive a free trip, this share of passengers can be expected to be insignificant compared to the total number of trips made. The way in which the delay is calculated by the WMATA (i.e.: maximum vehicle travel time + maximum headways + walking times) could positively contribute to this share being insignificant. The reason for this is that for a possible fraudulent passenger, it would require them to consider both the vehicle headways and the walking times, in addition to the travel time, in order to determine how long they should wait before they get a refund.

Despite the reported differences between the estimated and experienced arrival delay distribution, the total numbers of delay per month seem to be roughly equal, as can be seen in Figure 5.7. These bar charts show the total minutes of delay, summed per month, for both the estimated and experienced arrival delays. As can be seen, the estimated arrival delays are generally slightly higher, with the exception of October 2017. However, the overall differences can be considered to be rather small. This seems to show that the differences, i.e., the underrepresentation of shorter delays and overrepresentation of longer delays, in delay distribution as seen in Figure 5.4 and Figure 5.5 nearly cancel out when aggregating over a month of time.

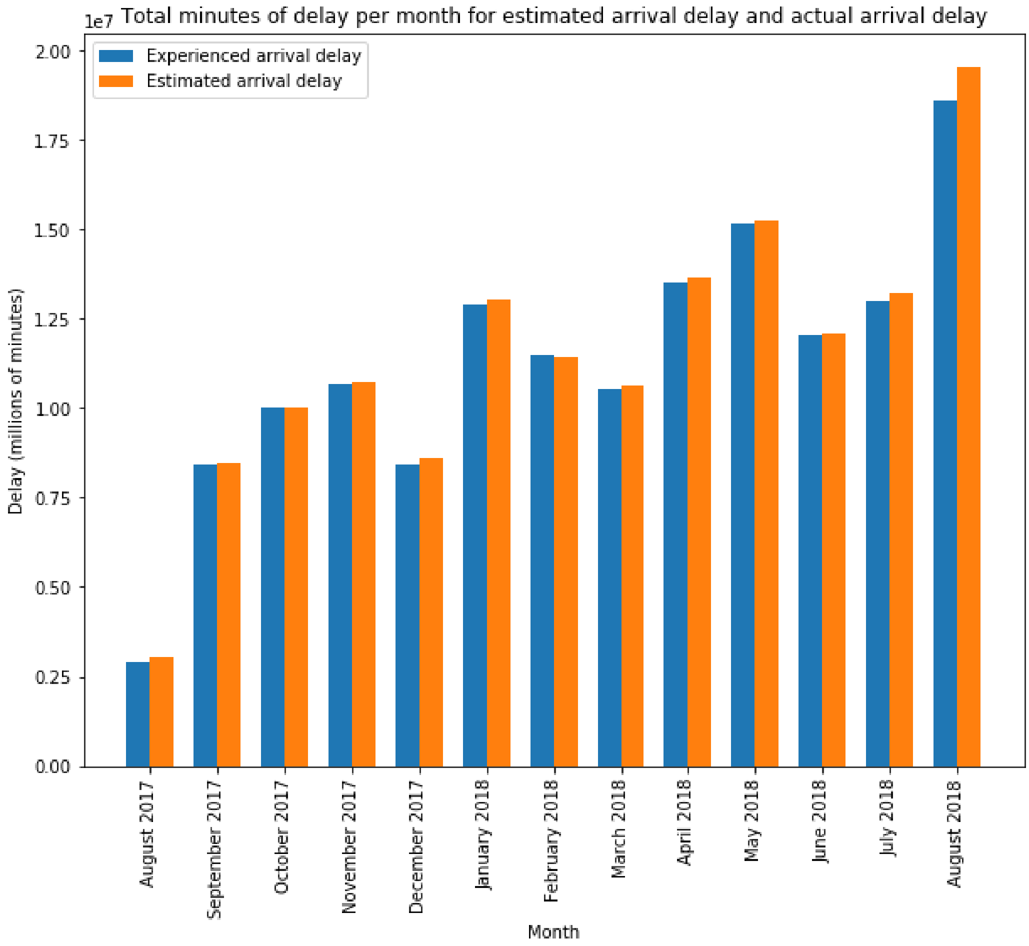

Figure 5.7: Bar chart for total estimated vs. actual arrival delays per month

For the remainder of this thesis, we will use the estimated arrival delays rather than the experienced arrival delays, apart from subsection 6.1.2 where we again briefly compare the estimated vs. experienced delays.

5.5. Refund-sensitive OD-pairs

Next to the general analyses of (refundable) delays and their distributions which has already been carried out, we also carry out a few other analyses. Using the original WMATA refund scheme as used in the case study as explained in chapter 6, as well as the estimated arrival delays as described in the section above, we will start by examining in two ways the amounts of refunds issued per origin-destination (OD) pair, in order to clarify where the largest 'monetary' bottlenecks are located for the operator WMATA. To this end, we count all trips as well as all refunded trips taken over the study period by OD-pair, with which we can calculate the percentage of trips taken per OD-pair that is being refunded. In Table 5.3, we can first find the ten OD-pairs with the largest amounts of refunds issued in *absolute* sense, i.e., without taking the total number of trips taken between this OD-pair into consideration, and subsequently the ten OD-pairs with the largest amounts of refunds issued in *relative* sense, i.e., sorting by the percentage of trips refunded. The column 'route' indicates the route that is the shortest between the corresponding OD-pair, i.e., which lines have been taken. Within this column, the silver line is denoted as SV, the red line as RD, the orange line as OR, and the blue line as BL.

Origin	Destination	Total trips	Refunded trips	%	Route
Wiehle Avenue	Foggy Bottom	127816	4896	4	SV
Wiehle Avenue	Farragut West	183413	4919	3	SV
Metro Center	*Wiehle Avenue*	138981	5271	4	SV
Smithsonian	*Wiehle Avenue*	87996	5490	6	SV
Shady Grove	Metro Center	256227	5583	2	RD
Shady Grove	Gallery Place	168324	5755	3	RD
Wiehle Avenue	Metro Center	134303	5956	4	RD
Shady Grove	Dupont Circle	175973	6205	4	RD
Wiehle Avenue	Smithsonian	98883	6212	6	SV
Shady Grove	Farragut North	389368	6603	2	RD
Spring Hill	Deanwood	232	32	14	SV >OR
Landover	*Largo Town Center*	848	117	14	OR >SV/BL
Vienna	*Largo Town Center*	1344	191	14	OR >SV/BL
Vienna	Morgan Boulevard	2544	366	14	OR >SV/BL
Largo Town Center	Landover	947	137	14	SV/BL >OR
New Carrollton	*Largo Town Center*	7178	1128	16	OR >SV/BL
Largo Town Center	*West Falls Church*	643	116	18	SV/BL >OR
Spring Hill	Farragut North	135	29	21	SV >RD
West Falls Church	*Largo Town Center*	806	190	24	OR >SV/BL
Largo Town Center	*New Carrollton*	6316	1597	25	SV/BL >OR

Table 5.3: Largest amounts of refunds issued per OD-pair, in absolute and relative sense

Based on this table, we can make a number of observations. Firstly, it should be noted that there is no 'overlap' between OD pairs with the most refunds in an absolute and relative sense. Furthermore, remarkably, almost all of the OD-pairs in both of the tables have at least one terminal station included in them. These terminal stations have been marked *italic* in the table.
Regarding the largest amounts of refunds issued per OD-pair in an absolute sense, we notice that all OD-pairs include two terminal stations, being Wiehle Avenue and Shady Grove. This could faintly point us towards the conclusion that both Wiehle Avenue and Shady Grove are two terminal stations that are more prone to delays occurring, however exact causes for these delays cannot be deducted from the available data, apart from the fact that the longer a trip is could make it more prone to accumulating a delay.
The other 'ends' of the OD-pairs are predominantly more centrally located stations that can be reached from the aforementioned two terminal stations without a transfer, such as Metro Center, or Gallery Place. These stations are also among the stations with the highest ridership on the network, which might explain their presence in this table as on average more trips can be expected to either begin or end there.

Considering the largest amounts of refunds per OD-pair in a relative sense, i.e., the amount of refunds divided by the ridership on the respective OD-pair, we can again discern a large share of terminal stations. However, remarkably, all of these OD-pairs do involve a transfer, as opposed to the previously discussed set of absolute largest OD-pair-based refunds. For instance, the OD-pair with the relatively largest amount of refunds issued is Largo Town Center to New Carrollton. Remarkably, this transfer includes taking the connecting train in the 'reverse' direction. This might be an indication that these connections are not well 'tuned' to each other.
A final remarkable point is the fact that within the OD-pairs with the largest amount of refunds, merely four of the six lines in the network are being included, namely the silver, red, orange and blue lines. The causes for the other two lines not being present at all cannot be determined with certainty from the data that is available. Possible causes could however be more robust operations on these lines, or a bottleneck at points where lines merge (such as the junction of the blue/silver and orange lines before Stadium-Armory station, or the junction of the silver and orange lines before East Falls Church station).
To make it clearer between which OD-pairs the most refunds are granted, Figure 5.8 shows the OD-pairs as arrows on a map of the Washington surroundings.

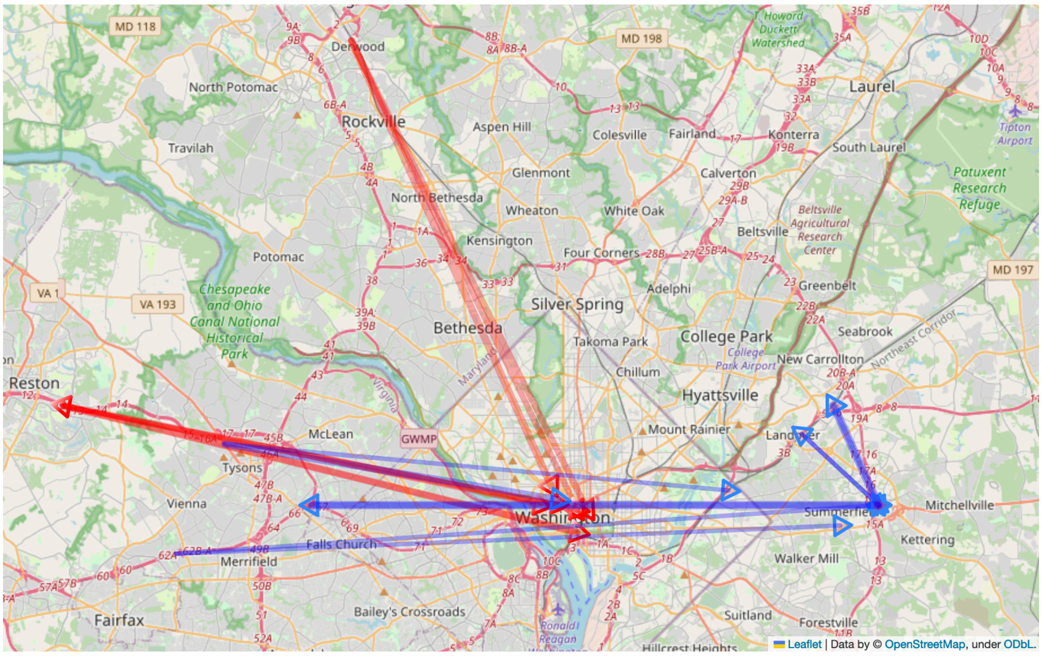

Figure 5.8: Flow map for most refund-sensitive OD-pairs. The OD-pairs with the most refunds in absolute sense are shown with red arrows, and the OD-pairs with the most refunds in relative sense are shown with blue arrows. The thickness of the arrow indicates respectively the OD-pair with the largest amount of refunds, and the OD-pair with the highest percentage of refunds.

6 Case study results

Using the methodology as described in chapter 2, in this chapter, the case study results will be presented. In section 6.1 and section 6.2, the link between delays and respectively refunds paid and amounts of refunds given will be examined. Furthermore, the refund schemes that were created and presented in section 5.2 will be evaluated in section 6.3.

6.1. Link between total delay and total refunds paid

In this section, the results of the delay/refund link analysis are presented, with the methodology as described in section 2.3.

6.1.1. Delay-refund link

Data processing and outlier analysis

In this section, we will create and analyse scatterplots to examine the link between delays and refunds. As described in section 2.3, we sum per day of the study period all (estimated) delays encountered over one day, as well as all refunds paid during one day. The refund scheme used is in correspondence with the original refund scheme used by the operator WMATA, as described in subsection 5.1.3.
When initially plotting and examining the data points, two notable outliers were spotted, for which the average delay per trip was around 7 minutes and the average refund per trip was around $ 1.75. A closer examination of these two outliers showed, however, that the total number of passengers was considerably lower on these two days: 1,638 and 1,699 trips, in large contrast with the average number of trips per day during the study period, which is 435,889. The entries in the disruption log file present, however, do not provide any conclusive evidence on why the number of trips was so limited. It could however be that a service interruption took place, during which only a very limited number of trips could be completed, which had as such a much higher delay than average. However, as we do not possess any information on total (scheduled or unscheduled) service interruptions, we cannot determine this with certainty. For completeness, the plot still containing the outliers can be found in Appendix C.
Notably, the study period contained one more day of data with a trip count that was way below average with merely 775 trips taken, but this day contained relatively normal delay-refund proportions, with averages of 3.66 minutes of delay per trip and $0.26 of refund per trip, which one could consider to fit in the 'normal' range given the other data points.
For the subsequent plots as well as the linear regression analysis which will be discussed below, we have removed the two discussed outliers from the set of data points, as these two points cannot be expected to fully contribute to a reliable cross-section of data to carry out the regression analysis on.

Linearity analysis

Overall, when looking at the data points, a form of linearity between the delays and refunds indeed seems to be present. Two 'strains' are present in the data points. On a closer inspection, these turn out to originate from weekend and week days. The most probable cause for this is that the fare scheme of WMATA includes a flat regular fare of $2.00 per trip taken on weekend days, as opposed to the fare of $2.00 to $6.00 during weekdays.

Regarding the spread of the data points, the majority of the data points seem to be concentrated in the lower left corner of the plot, roughly with delays per trip ≤ 0.5 and refunds per trip ≤ \$0.10. This does however correspond with the average delay and refunds per trip per day, which are respectively around 0.3 minutes and \$0.05. Furthermore, the refunds per trip seem to be heteroscedastic, i.e., the variance of the average number of refunds per trip seems to increase with the average delay per trip. This might partially be caused by the fact that these data points can be considered to be rather large deviations from the mean daily which were reported before, as well as that they are relatively few in number relative to the roughly 350 data points. For instance, only 22 data points had an average delay per trip above 1.5 minutes.

Model fitting

To further confirm the overall linearity, we carry out a linear regression analysis. Initially, to account for the two strains in the data in one model, a mixed effects model with a random slope (categorising the weekend and week days) was tried. However, the coefficients of this random slope model were less reliable with a p-value of 0.068. Hence, a more 'traditional' linear regression analysis has been carried out. A total of three linear regression analyses were done: one that takes all data points into account, one that takes only the weekend day data points into account and one that takes only the weekdays data points into account. In Figure 6.1, the two resulting regression lines for the weekend days and weekdays are plotted alongside the data points. We have omitted the regression line for all days from Figure 6.1 for better readability. The regression results for all days can however still be found in Table 6.1, along with the regression results discerning between weekend days and weekdays.

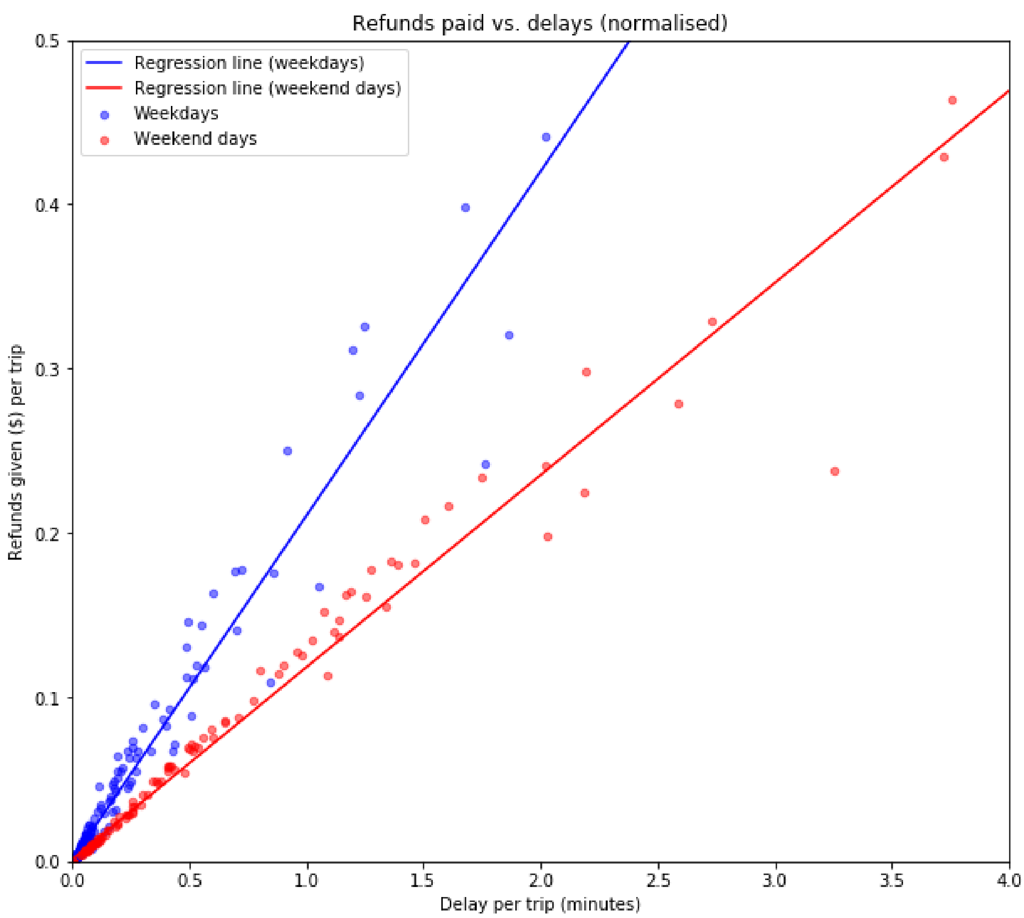

Figure 6.1: Link between delays and refunds, discerning between weekdays and weekend days, with regression slopes added

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Parameter	Result (all days)	Result (weekdays)	Result (weekend days)
Slope	0.131	0.210	0.117
Intercept	0.007	0.0006	0.0012
R^2-value	0.933	0.974	0.987
p-value	< 0.0001	< 0.0001	< 0.0001
Standard error	0.0026	0.0025	0.001

Table 6.1: Regression results of delay-refund link for all days, weekdays, and weekend days of the study period

As can be seen, the reliability of the estimations is rather high when taking all data points into account, however it increases even further when discerning between weekend days and weekdays, when examining the corresponding R^2-values.

6.1.2. Influence of using delay estimates on delay-refund link

In this section, we will carry out the delay-refund link analysis again, but we will now discern between the estimated arrival delays and the experienced arrival delays, to see to which extent they differ. This might be relevant for situations in which delay estimation data is not (readily) available. We again sum the delays and refunds per day for both of the data sets. Interestingly, upon first examining the data points, the same two outlier days, containing the same two days as described in subsection 6.1.1, were again present. This does point us towards the cautious conclusion that the information contained in the smart card data was valid. The exact cause of these two outliers being present, other than that they are based on a substantially smaller amount of trips taken during the two corresponding days, remains however unknown. After again removing the outliers from the data set, we again carry out a regression analysis, of which the results are shown in Table 6.2. We then plot the delay-refund points alongside with the regression lines in Figure 6.2 for the experienced and estimated arrival delays. In the plot in Figure 6.2, the two outliers have already been removed.

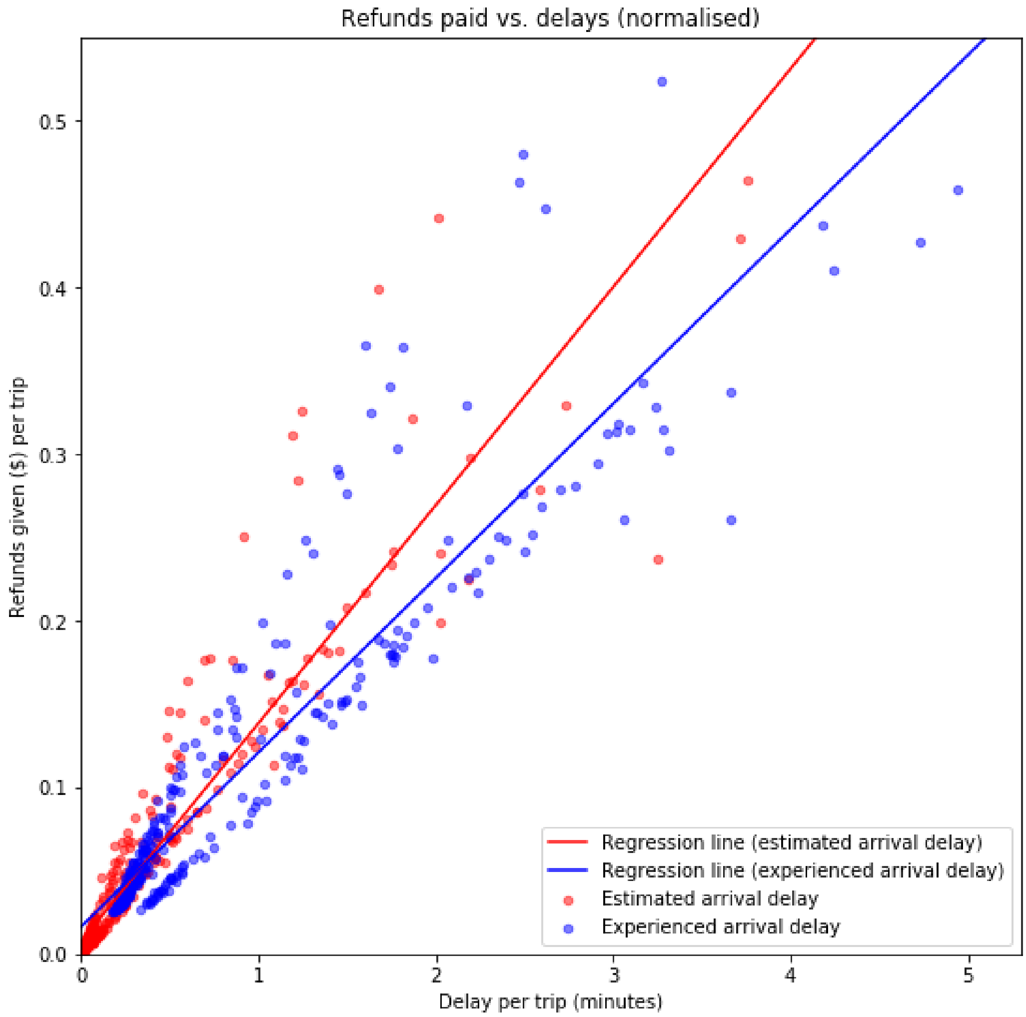

Figure 6.2: Link between delays and refunds, discerning between estimated and experienced arrival delays, with regression slopes added

.

Parameter	Result (experienced arrival delay)	Result (estimated arrival delay)
Slope	0.10	0.13
Intercept	0.015	0.007
R^2-value	0.928	0.933
p-value	< 0.0001	< 0.0001
Standard error	0.002	0.002

Table 6.2: Regression results of delay-refund link for all days, discerning between experienced and estimated arrival delays

As we can see from this figure and table, generally, the slope of the estimated link between delays and refunds is slightly steeper. This is however in line with the findings reported in section 5.4, where it was shown that the estimated arrival delays seem to be slightly overestimated compared to the experienced arrival delays. This can be expected to create a larger amount of refunds, and hence, a link between delays and refunds that yields more refunds per minute of delay per trip taken. These findings might be relevant in cases where the arrival delay estimates we created are unavailable, for instance for a public transport operator who would like to predict the number of refunds that a certain (planned) disruption/detour with corresponding delays could yield.
Also in line with expectations, however, the reported R^2-value is slightly larger for the estimated delay. This could be expected as the variance in delays can also be expected to be smaller for the estimated

delays, due to the fact that the outliers in the trips caused by erroneous individual behaviour are 'filtered out'.

6.2. Link between delay and number of refunds

Next to the link between delays and the total amounts of refunds that have been paid, aggregated per day, we also examine the link between the number of refunds that have been given, regardless of their magnitude. The reason for this is the fact that only looking at the number of refunds eliminates a possible bias due to predominantly longer or shorter trips being taken on a day, i.e., a data point. The average trip length would yield correspondingly larger or smaller fares, if during weekdays.
After removing the same outliers that were discussed in the preceding section and were again present in the data, we again plot the data points, each showing one day of delays/refunds divided by the number of trips in Figure 6.3. The figure already includes the regression line following the same procedure as in the preceding sections. The regression coefficients are displayed in Table 6.3.

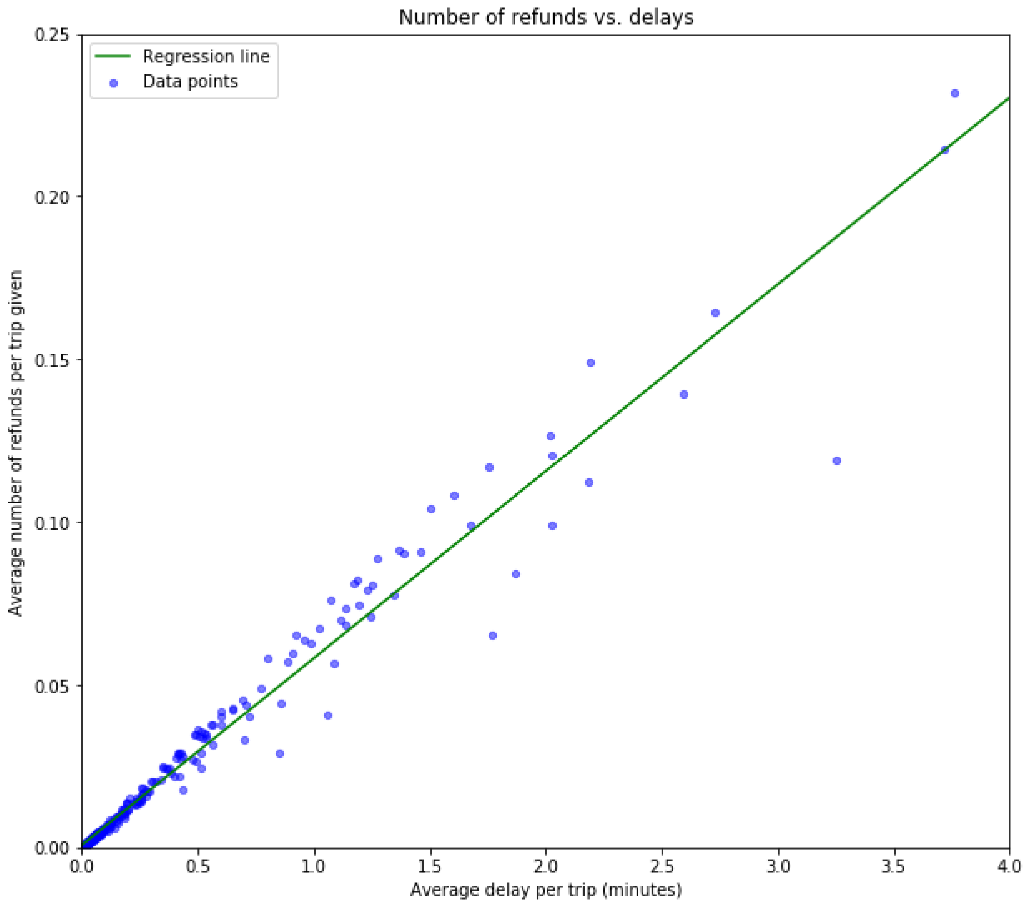

Figure 6.3: Link between delays and number of refunds, with regression slopes added

.

Parameter	Result
Slope	0.137
Intercept	-0.006
R^2-value	0.883
p-value	< 0.0001
Standard error	0.004

Table 6.3: Regression results of link between delay and number of refunds for all days of the study period

We can see that a form of linearity is again present, which is in line with the results from the preceding section. As a difference to the link between delays and refunds paid, the two 'strains' that were present in the data points are now not present anymore. This is however in line with expectations, as the distinction between weekend days and weekdays due to the fare difference is now not present anymore. Overall, we can now see more or less linear behaviour occurring, although there is still notable heteroscedasticity, i.e, the variance of the average number of refunds per trip seems to increase with the average delay per trip.

6.3. Evaluation of created refund schemes

In this section, we will carry out the performance evaluation of the different refund schemes as defined in subsection 5.2.2. We will first examine the results of the various refund schemes, by looking at the commonality of refunded trips as well as the the predominating OD-pairs in each refund scheme. Subsequently, we will show a similar plot to the delay-refund scatterplots as found in section 6.1, but now with all different refund schemes. Finally, we will assess the performance of the refund schemes according to the assessment indicators as defined in section 4.2, and present a few considerations for choosing a 'best' refund scheme.

6.3.1. Commonality comparison of refund schemes

In this section, we will look into the similarities and differences of the refund schemes that we created. Before we make the distinction between the original fare or a flat fare refunded, we will first have a look at some characteristics which are independent of the refund *paid*, namely which trips and which OD-pairs are refunded under the different refund schemes, and how this changes with the delay type and threshold. We have not included the refund schemes that use the generalised arrival delay, as the threshold for issuing a refund is in this case not an individual trip, but a punctuality metric aggregated over multiple trips, and the logic behind it is considered to be too different to make meaningful comparisons.

Commonality of trips

To start with, we will examine the commonality of the trips refunded and how this changes amongst the different refund schemes. To this end, in the commonality matrix shown in Table 6.4, the percentages of trips that are identical amongst the respective refund schemes are shown. We achieved this by, pairwise, first determining which of the two refund schemes had the smallest amount of refunded trips, and subsequently comparing all trip IDs which were present in the data, to see how much of the trips 'matched'. In the upper row, A and D indicate arrival and departure delay, and the subsequent number the delay threshold. The numbers between brackets in the upper row indicate the total number of refunded trips under the respective refund scheme. As an example, out of D_15 and A_20, D_15 had less refunded trips than A_20, so we calculated how many of the 62,295 trips refunded under the D_15 refund scheme were also refunded under the A_20 refund scheme.

A_10 (1,743,334)	**A_15 (707,180)**	**A_20 (339,634)**	**D_10 (195,594)**	**D_15 (62,295)**	**D_20 (28,969)**	
X	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	**A_10**
	X	100.0 %	55.3 %	100.0 %	100.0 %	**A_15**
		X	31.5 %	65.9 %	100.0 %	**A_20**
			X	100.0 %	100.0 %	**D_10**
				X	100.0 %	**D_15**
					X	**D_20**

Table 6.4: Commonality of refund schemes on trip level

We can firstly conclude from this table that for the majority of refund scheme 'pairs', the trips are fully common. For many entries, this is not very surprising, as, for instance, all trips with an arrival delay of 15 minutes will also be refunded under the 10-minute arrival delay refund scheme. There are three exceptions to this, being the 10-minute departure delay and 20-minute arrival delay, the 10-minute departure delay and 15-minute arrival delay, and the 15-minute departure delay and 20-minute arrival delay refund schemes. The 10-minute departure delay and 20-minute arrival delay have the least trips in common. This might be a sign that for the available data, a trip starting with a 10- or 15-minute departure delay is on average less likely to later on receive an arrival delay which is substantially larger than 10 or 15 minutes; in other words, a large departure delay is not always a sign for a subsequent accumulation of delays which results in a much larger arrival delay.

Commonality of OD-pairs

Next to the commonality analysis of the trips refunded, we will also analyse the commonality of OD-pairs, i.e., which OD-pairs are most commonly refunded under the different refund schemes. We carry out a somewhat similar analysis to the one carried out in section 5.5, comparing both the most refunded OD-pairs in absolute and in relative sense. However, we perform this analysis now for all refund schemes that have been described in the introduction to this section. The results can be found in Table 6.5, although for readability, we now merely show the station codes which were used whilst processing the data. We will however highlight some of the predominant OD-pairs found in the findings after the table. For completeness, the station codes can be found in Appendix B. The numbers between brackets show the 'absolute' top-ranked number of refunded trips taken on each OD-pair, and the percentage between brackets shows the percentage of 'relative' top-ranked refunded trips taken on each OD-pair.

	10m AD	**15m AD**	**20m AD**	**10m DD**	**15m DD**	**20m DD**
#1 abs	15 - 2 (6603)	15 - 2 (3900)	15 - 2 (2330)	88 - 90 (1082)	39 - 82 (554)	13 - 15 (384)
#2 abs	95 - 43 (6212)	15 - 3 (3353)	15 - 3 (2015)	21 - 23 (1029)	50 - 54 (536)	50 - 54 (329)
#3 abs	15 - 3 (6205)	15 - 1 (3151)	15 - 1 (1921)	81 - 82 (1025)	18 - 23 (521)	39 - 82 (328)
#4 abs	95 - 1 (5956)	95 - 43 (3066)	15 - 16 (1911)	39 - 82 (962)	13 - 15 (509)	81 - 82 (300)
#5 abs	15 - 16 (5755)	95 - 1 (3001)	90 - 30 (1542)	18 - 2 (893)	81 - 82 (494)	25 - 26 (283)
#1 rel	80 - 54 (25.3 %)	80 - 54 (15.2 %)	80 - 54 (9.4 %)	88 - 87 (7.9 %)	6 - 33 (4.4 %)	6 - 33 (4.4 %)
#2 rel	88 - 80 (23.6 %)	94 - 2 (10.4 %)	93 - 33 (8.8 %)	88 - 90 (6.1 %)	49 - 79 (3.3 %)	52 - 53 (2.9 %)
#3 rel	94 - 2 (21.5 %)	93 - 33 (9.6 %)	54 - 64 (7.9 %)	81 - 82 (5.0 %)	52 - 53 (3.2 %)	49 - 79 (2.8 %)
#4 rel	80 - 88 (18.0 %)	95 - 79 (9.0 %)	64 - 54 (6.5 %)	49 - 79 (4.9 %)	79 - 80 (2.9 %)	79 - 80 (2.1 %)
#5 rel	54 - 80 (15.7 %)	54 - 64 (8.7 %)	41 - 75 (6.0 %)	6 - 33 (4.7 %)	19 - 93 (2.7 %)	52 - 63 (2.1 %)

Table 6.5: Commonality of refund schemes on OD-pair level

From this table, we can firstly conclude that the 'variability' of OD-pairs, i.e., the number of OD-pairs appearing, seems to be larger for the departure delay-based refund schemes. This is already apparent from the #1 most refunded OD-pair in both absolute and relative sense, which is constant for all delay thresholds throughout all arrival delay-based refund schemes. Furthermore, when not accounting for 'doubles' (i.e., 15-2 or 2-15), only seven and six OD-pairs appear throughout all arrival-delay based OD-pairs refunded in absolute sense and relative sense, respectively. Interestingly, for the most refunded OD-pairs in absolute sense, no such 'doubles' appear, whereas for the most refunded OD-pairs in relative sense, many 'doubles' appear.

For the number of refunds issued for the departure delay-based refund schemes, the number of OD-pairs appearing is equal for the most refunded OD-pairs in absolute sense compared to the most refunded OD-pairs in relative sense (nine for both the absolute and relative top-5), however generally, there seems to be more variability for both of these in the departure delay-based refund schemes than the arrival delay-based refund schemes. However, this might also partially be caused by the fact that less trips are included for the departure delay-based refund schemes, which could create less 'clustering' and more 'randomly' refunded trips. Remarkably, also no 'doubles' appear for both the absolute and relative top-5 of departure delay-refund schemes.

6.3.2. Delay-refund plots of refund schemes

Next to the delay-refund scatter plots with corresponding regression lines that we showed in the preceding section 6.1, we also create similar plots for the refund schemes created in subsection 5.2.2. We however also here omit the refund schemes using the generalised arrival delay, as the amounts of refunds given in these schemes are calculated in a very different way, which do not involve using trips from individual days. The plots can be found in FIGURE. We merely plot the regression lines in this figure, as plotting all data points would severely reduce the readability of the figure. Furthermore, in TABLE, we show the regression parameters of the slope. We omit the p-values, R^2-values, and intercept values, for improved readability. All p-values were well below 1×10^{-100}, all R^2-values were above 0.9, and all intercept values were (in absolute sense) below 0.001.

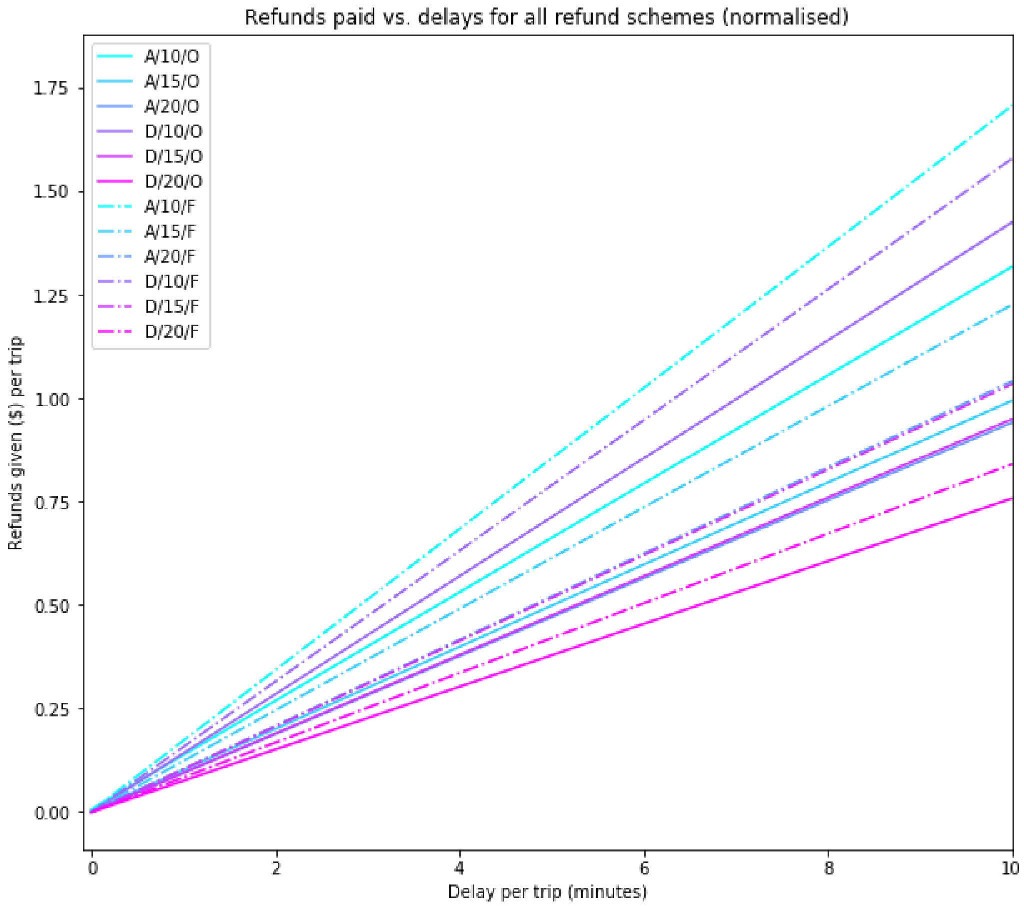

Figure 6.4: Delay-refund link of all refund schemes, with only the regression slopes added

RS	SP	RS	SP
A/10/O	0.13	**A/10/F**	0.17
A/15/O	0.10	**A/15/F**	0.12
A/20/O	0.09	**A/20/F**	0.10
D/10/O	0.14	**D/10/F**	0.16
D/15/O	0.09	**D/15/F**	0.10
D/20/O	0.08	**D/20/F**	0.08

Table 6.6: Regression slope parameters for all refund schemes

Based on the figure and table, we can firstly observe that for a constant delay type and threshold, the slope for the flat-fare refund schemes is always steeper than that of their original-fare counterpart. It should be noted, however, that there is notable variability in the steepness difference; for instance, for the 10-minute departure delay, the difference is 0.02, however, for the 10-minute arrival delay, the difference is 0.04.
Overall, we can see the steepest slope for the 10-minute arrival delay refund scheme with a flat fare, i.e., the largest amounts of refunds per minute of delay per trip are granted when using this refund scheme. The smallest amount of refunds per minute of delay per trip is granted when using the 20-minute departure delay original fare refund scheme.

6.3.3. KPI evaluation of refund schemes

Next to the commonality analysis and the delay-refund plots of the created refund schemes, we also use the assessment indicators that we created and presented in section 4.2 to evaluate their performance. The numeric results of these KPIs, indicated by their name and by the refund scheme that was used as input for them, are shown in Table 6.7. To make it more clear what is meant, we use the following abbreviations: **RS** = Refund Scheme, **DT** = Delay Threshold (minutes) **RG** = Refund Given, **AD** = Arrival Delay, **DD** = Departure Delay, **GAD** = Generalised Arrival Delay **OF** = Original Fare, **FF** = Flat Fare, **PST** = Part of Seasonal Ticket

RS	DT	RG	Refunds per trip (RPT) (%)	Delay Ratio (DR) (%)	Revenue to Refund (RTR) (%)	Time loss compensation share (TLCS) (%)
A/10/O	10 AD	OF	1.11	1783	1.07	8.39
A/15/O	15 AD	OF	0.45	2462	0.46	3.58
A/20/O	20 AD	OF	0.22	3116	0.23	1.81
D/10/O	10 DD	OF	0.12	4809	0.10	0.77
D/15/O	15 DD	OF	0.04	7229	0.03	0.2
D/20/O	20 DD	OF	0.02	9499	0.01	0.1
A/10/F	10 AD	FF	1.11	1783	1.08	8.48
A/15/F	15 AD	FF	0.45	2462	0.43	3.44
A/20/F	20 AD	FF	0.22	3116	0.21	1.65
D/10/F	10 DD	FF	0.12	4809	0.12	0.95
D/15/F	15 DD	FF	0.04	7229	0.39	0.3
D/20/F	20 DD	FF	0.02	9499	0.18	0.14
G/80%/S	80% GAD	PST	0.01	1176	0.19	0.24
G/85%/S	85% GAD	PST	0.03	1177	2.02	2.54
G/90%/S	90% GAD	PST	0.15	1176	9.05	11.4

Table 6.7: Results of KPI evaluations of refund schemes

When examining the table and comparing the numeric results of the KPIs in a few different ways, we can make the following conclusions:

Arrival vs. departure delay

- Firstly, obviously, the values for RPT, RTR and TLCS are smaller for the departure delay-based refund schemes than for arrival delay-based refund schemes, as these delays can be expected to be smaller due to the estimation methodology.
- When examining the 'decay', i.e., how much the different KPI values decrease or increase with a different delay threshold, we can see that this decay is quicker for the departure delay-based refund schemes. As an example, for the arrival delay-based refund schemes, the amounts of refunds per trip with a 10- and 15-minute delay threshold are respectively 2.5 and 5 times larger than the amount of refunds per trip with a 20-minute delay threshold. For departure delay, these differences are a factor 3.3 and 7. In other words, the delay threshold choice seems to have a larger effect on the number of refunds for departure delay-based refund schemes than for arrival

delay-based refund schemes. Similar effects to the one described above can be seen for the revenue-to-refund ratios and time loss compensation shares.
- Overall, we can conclude that the sensitivity to the delay threshold chosen is stronger for departure delay than for arrival delay.

Original fare vs. flat fare refund

- Firstly, it should be noted that the first two KPIs are obviously the same for original fare refunded vs. flat fare. This can be explained by the fact that the amounts of trips that are refunded under the original fare vs. flat fare are exactly the same.
- For a 10-minute (both arrival and departure) delay threshold, the revenue-to-refund ratios for the operator are slightly larger, however, they 'decay' quicker with a larger delay threshold. The cause of this is unknown, but it might be caused by the fact that a smaller delay threshold would lead to more short trips being included (for which it could be expected that the delays are smaller). These shorter trips would have an original fare that is less, which would lead to more cases in which a flat-fare refund scheme 'overcompensates' the original fare paid.
- Also, the time loss compensation share is larger for a 'flat fare' refund, and the 'decay' with a larger delay threshold is largely the same. The difference is larger between the departure delay-based refund schemes (i.e. between 4-6 and 10-12) than between the arrival delay-based refund schemes (i.e. between 1-3 and 7-9). This might again be partially explained by the fact that the delay threshold sensitivity is larger for departure delay than for arrival delay.

Generalised vs. individual delay

- As can be seen from RPT, refunds given per trip are much less for generalised vs. individual arrival delays. This can be somewhat expected as only 10 per cent of the trips have been assumed to be taken on a season ticket. However, the refund issued in case of a refund is obviously way larger, which explains the larger values for the two KPIs based on
- The choice for a delay threshold for generalised arrival delay refund schemes is extremely important; this can especially be seen for KPIs RTR and TLCS, where a 10 per cent decrease of the delay threshold creates a more than tenfold increase in revenue-to-refund ratios and time loss compensation share.
- The values for DR remain more or less constant for all the generalised arrival delay refund schemes, in comparison to the individual arrival delay refund schemes. The value, however, is more or less in line with what one could expect given the arrival delay threshold of 5 minutes that was used for calculating the punctuality index.

In order to draw additional conclusions from the numbers that were presented in Table 6.7, we have also visualised them using scatter plots in which marker size and colour are varied. The result of this can be seen in Figure 6.5.

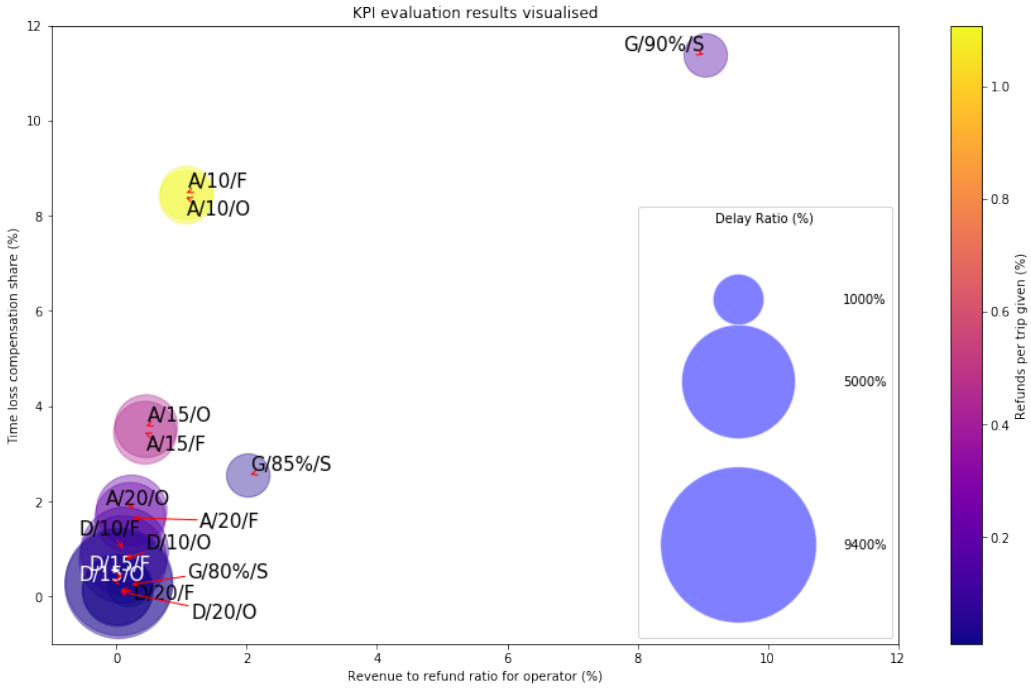

Figure 6.5: Results of KPI evaluations of refund schemes, visualised

Using this figure, we can additionally make some conclusions, mainly about the general deviation or similarity of the KPI results for all refund schemes. It is firstly clear that the refund scheme G/90%/S is very far removed from the other results, which emphasises both the very large revenue-to-refund ratios for the operator but also the large time loss compensation share that comes along with it. Also, G/85%/S is notably removed from the other refund schemes, albeit less extremely than its 90-percent counterpart. Furthermore, the refund schemes using flat fare refunds vs. original fare refunds are in many cases very close together, such as for a 10- or 15-minute arrival delay. There is notable cluttering occurring for all other refund schemes, which indicates that the revenue-to-refund ratios for the operator and time loss compensation share are both very low.
Notably, the refund schemes making use of a 10-minute arrival delay feature a relatively small revenue-to-refund ratio for the operator and at the same time a relatively large time loss compensation share, indicating that these two KPIs are not mutually exclusive, which could come to mind given the fact that both of them involve the monetary effects of the refunds (being) paid.

6.3.4. Refund scheme optimisation

In order to identify a possible 'optimal' refund scheme, we can determine the combination of KPI results that could be considered the 'best' combination, from the perspectives of both a public transport traveller and a public transport operator. We expect both the customer and operator to wish for a Refunds per Trip (RPT) score that is as low as possible, albeit this could be limited to or would be especially relevant in cases of manual reimbursement, as a reimbursement creates manual action and subsequent labour for both customers and operators. With automatic reimbursement, this can be considered to be less relevant. The Delay Ratio (DR) score can be considered to be irrelevant for both customers and operators. The revenue to Refund ratio (RTR) can be expected to be irrelevant for the customer, but the operator can be expected to wish for these to be as low as possible. Finally, the time loss compensation share (TLCS) can be expected to be desired to be as low as possible for the customer, but irrelevant for the operator. To summarise, Table 6.8 shows the possible 'experiences' that both of these parties could have per KPI.

	Customer	Operator
RPT	low	low
DR	-	-
RTR	-	low
TLCS	high	-

Table 6.8: KPI considerations for customer and operator

Based on these requirements, we rank the KPI results as found in Table 6.7 as follows: RPT scores from lowest (1) to highest (15), RTR scores from lowest (1) to highest (15), and TLCS scores from highest (1) to lowest (15). Subsequently, we add the 'ranked' scores. The lowest resulting score then yields the 'best' refund scheme, according to these three KPIs as observed from both the operator's and traveller's perspective. These scores can be found in Table 6.9. We add the scores for the KPIs RPT, RTR and TLCS for situations with manual reimbursement, called S1 in the table, as well as the scores for the KPIs RTR and TLCS for situations with automatic reimbursement, called S2 in the table.

	RPT	#	RTR	#	TLCS	#	S1	S2
A/10/O	1.11	14	1.07	12	8.39	3	29	15
A/15/O	0.449	12	0.455	11	3.58	4	27	15
A/20/O	0.216	10	0.23	8	1.81	7	25	15
D/10/O	0.124	7	0.0983	3	0.773	10	20	***13***
D/15/O	0.0396	5	0.0311	2	0.244	12	19	14
D/20/O	0.0184	2	0.014	1	0.11	15	***18***	16
A/10/F	1.22	15	1.08	13	8.48	2	30	15
A/15/F	0.487	13	0.437	10	3.44	5	28	15
A/20/F	0.232	11	0.21	7	1.65	8	26	15
D/10/F	0.144	8	0.121	4	0.951	9	21	***13***
D/15/F	0.0432	6	0.385	9	0.303	11	26	20
D/20/F	0.0201	3	0.179	5	0.141	14	22	19
G/80%/S	0.00956	1	0.189	6	0.238	13	20	19
G/85%/S	0.0326	4	2.02	14	2.54	6	24	20
G/90%/S	0.147	9	9.05	15	11.4	1	25	16

Table 6.9: KPI ranking and summations of ranking scores

Based on these results, we can identify the refund schemes that have the 'best' combination of KPI results as described earlier. For a situation with manual reimbursement (i.e., taking also the RPT score into account), the best combination of KPI results is given by the refund scheme D/20/O, i.e. a refund scheme that refunds the original fare at a 20-minute departure delay. This refund scheme however also yields the smallest TLCS score, meaning that the smallest percentage of time losses is compensated with this refund scheme. For a situation with automatic reimbursement, the refund schemes D/10/O and D/10/F perform equally well regarding the 'balance' between revenue to refund ratio and time loss compensation share. These refund schemes both use a 10-minute departure delay, which therefore can be considered to perform 'best' according to these ranked KPIs.

7
Discussions and conclusions

In this chapter, we will return to the research questions posed at the beginning of this document and point out the most important contributions of this thesis. Furthermore, we will outline some discussion points that came along with the research carried out. These include the methodology limitations and assumptions, and the subsequent additional research opportunities that these limitations and assumptions might yield.

7.1. Key findings

The key findings of this research consist of both the answers to the research questions, which we will address in subsection 7.1.1, as well as the contributions of this research to the scientific state of the practice, which will be addressed in subsection 7.1.2.

7.1.1. Answers to research questions

In the introduction, we have defined several subquestions that allowed us to eventually answer the overarching research question. We will now address the answers to the sub-research questions in the order in which they were presented in the introduction.

Which forms of passenger delay-based refund schemes are currently existing in urban public transportation?

Regarding the state of the practice, we found out through surveying the internet that out of the 57 cities within Europe and North America with 1) a population of over 500,000 and 2) a metro(-like system), 30 used a form of delay refund scheme. Moreover, it should be noted that very roughly speaking within Europe, refund schemes seem more common in the northwestern half than in the southeastern half. Furthermore, the predominant form of delay that is used for the refund scheme is departure delay.

Whilst executing the survey and categorising results, we, however, also encountered a number of caveats. Firstly, as already mentioned in section 3.2, the findability of refund schemes can sometimes be considered to be below average, with the information about it sometimes merely retrievable from the general passenger terms and conditions (Brussels), or the information only being available on news websites but not being relayed by the information provided by any operator (Italy). This might be a threshold for passengers to actually receive a refund, even when eligible for it. However, even when the information about refund schemes is clearly included on an operator's website, not all passengers eligible for a refund might actually claim it, as manual action will always be required. The effort required in some cases, for instance filling a form out that is sometimes only available at an operator's office, and sending it, might not be considered proportionate by passengers with the sole result being a reimbursement of the fare of one journey. With the ever-increasing use of smart cards (for instance in nearly all public transport systems in the Netherlands), especially when directly linked to a passenger through an account, operators using tap-in and tap-out data might want to consider integrating their refund scheme into these smart card systems, for instance in a similar manner to TfL and WMATA. One could argue that this could increase the operator's fairness towards the passengers, with performance that is below average automatically being compensated rather than manual action being still required.

What are the design aspects of creating urban public transportation delay-based passenger refund schemes?
By categorising and examining the factors that varied among the different refund schemes as found in the survey results, we can identify the most important design aspects of refund schemes. These are firstly the delay type (i.e., the form of delay that is used as a basis, such as departure delay or arrival delay) as well as the delay threshold (i.e., the change in either headway or scheduled arrival/departure time). The next design aspect is the actual refund given, which can take place automatically or manually and can consist of a fixed monetary amount, the reimbursement of the original fare or a part of a subscription ticket, a free travel voucher, or the cost of alternative transport refunded. These design aspects can be used by an operator when establishing a delay refund scheme.

To what extent is there a relation between total passenger time losses and refunds granted?
When examining the results of the delay-refund link analysis, we can state that indeed a form of linearity between delays encountered and refunds given seems to be present. This could create some new possibilities to link delays to refunds given. For instance, with recent new delay prediction methods arising such as found in Yap and Cats (2021), the corresponding refunds given could possibly also be predicted in this way. This has as of today to our knowledge not been attempted yet. However, if this were to work, it could be taken into consideration for a public transport operator who has a refund scheme in place, for instance when deciding between different scenarios of schedule changes required to carry out maintenance, and as such the delays that the schedule changes can be expected to yield.
A consideration to make when creating possible applications of this delay-refund link could be the discrepancy between the estimated delays and the estimated delays, as discussed in subsection 6.1.2. In this section, it was shown that the slope of the delay-refund curve seems to be less steep for experienced arrival delays. This discrepancy might be relevant when applying the aforementioned delay prediction methods, as the actual refunds that an operator receives might deviate accordingly.
To conclude, it should in general be noted that the parameters found in this research, such as the slope of the regression, cannot be expected to be easily transferable to other networks, as the distribution of delays, as well as the refund scheme itself, can be expected to influence the results to a great extent.

Which indicators can be used to assess the performance of different delay refund schemes?
To enable the comparison of different refund schemes, we have defined four key performance indicators, or KPIs. The inputs required to calculate these KPIs are the number of passengers, the number of refunds given, the amounts of refunds paid and a Value of Time (VoT). The four KPIs established in this thesis are however not an exhaustive list, as more KPIs could still be considered. These additional KPIs might, however, require different inputs.
Using these KPIs as well as a set of synthetic refund schemes that have been created according to the design aspects as well as case study data, we can make the following conclusions on the performance of different refund schemes.

What is the impact of different delay refund schemes given a fixed input of trips?
When using a constant input of trips, refund schemes that make use of a 'generalised' arrival delay and partially refund a seasonal ticket's price have been shown to yield smaller percentages of refunds per trip. However, the revenue losses for the operator have been shown to be much larger, especially when choosing a smaller delay threshold. In other words, it can be concluded that the refunds issued to passengers using this refund scheme are fewer in number; however, the actual reimbursements are much larger. Furthermore, these refunds are only given to passengers on a seasonal ticket. For a public transport operator, this could be considered an interesting ethical point of discussion: could only issuing refunds to 'loyal' passengers (as they possess a seasonal ticket) be an accurate way of rewarding this loyalty to the operator?
The importance of choosing the 'right' delay threshold, i.e., yielding the amount of refunds required to be paid which could be considered acceptable for the public transport operator, is significantly larger for the refund schemes that make use of generalised arrival delay, rather than individual departure or arrival delay. The reason for this is that the amounts of refunds paid are increasing or decreasing to a much larger extent with these generalised arrival delay refund schemes. On the other hand, arrival delay refund schemes seem to be more insensitive to the choice of delay threshold, whilst departure

delays are slightly more sensitive to this delay threshold choice.

When considering refund schemes using arrival delay rather than departure delay, the refund schemes using departure delay seem to represent time losses somewhat less accurately. However, this could change significantly when some factors are included that have not been able to be incorporated in this evaluation, such as alternative transport. We will discuss possible additional research topics related to this in subsection 7.2.3.

By using the KPI values and the possible perceived optimum for both the customer and the operator, we can determine which refund scheme could be considered the 'best' refund scheme. This would be a refund scheme using either a 10-minute or 20-minute departure delay. However, these conclusions are far from certain, for two main reasons. Firstly, the results are merely based on this case study data, but they can be expected to vary considerably depending on the situation such as the network, trips taken, punctuality during those trips, et cetera. Furthermore, they have merely been determined according to the perceived ranking of KPI values, which, to make more firm conclusions, could also be expected to need more input on the balance of 'acceptable' revenue losses and time loss compensation, for respectively the operator and the customer. We will return to possible ways to achieve this at the very end of this conclusion chapter.

Answering these five subquestions allows us to answer the main research question: **How can the current state of practice be used when designing passenger delay-based refund schemes with rail-based urban public transportation systems, and how can their performance be assessed?**

Due to the fact that the state of the practice of refund schemes has hardly been covered in scientific literature, the only way to get information on the state of the practice has been by surveying the internet and information that was provided there. This allowed us to determine the predominating design aspects for refund schemes, which are described in the corresponding research question answer. The performance of refund schemes can be evaluated by establishing a set of key performance indicators (KPIs), which have been tested on a set of refund schemes that have been created. This allows comparing the performance of different refund schemes. Although in our research, this evaluation has merely been carried out using a fixed input of trips, these KPIs could in a real-life setting also be used to monitor the performance of a refund scheme over time. Public transport operators might for instance use these to keep track of the (trends of) average refunds issued per trip, or the revenue losses that their refund scheme creates. This could be coupled with their punctuality goals, or even a goal to compensate a part of the passenger time losses encountered.

7.1.2. Contributions

The main contributions of this thesis to the scientific literature are twofold. Firstly, an overview has been created of parameters and design aspects that are currently in use for passenger delay-based refund schemes in urban public transportation. To the best of our knowledge, no literature has existed so far on these design aspects. Furthermore, a methodology has been developed to evaluate the performance of these refund schemes, as well as guidelines which could help determine an optimal refund scheme. This is however to a great extent dependent on the network characteristics, fares, and refunding properties.

7.2. Methodology discussions, further research topics

Although using the methodology as discussed in chapter 2, we have successfully carried out the research and shed more light on the topics discussed, there are also a few limitations that come with it. We will discuss them in the section to follow. We will also address the assumptions that we made throughout the research and the extent to which these assumptions might influence the results. Subsequently, we will provide some areas in which additional research might be beneficial.

7.2.1. Methodology limitations

Due to the summative nature of the delay component estimates, the method used to obtain the delays per trip cannot incorporate possible cases of trips where the experienced departure delay was larger than the arrival delay. This might for instance be the case when a passenger waits for a metro to arrive, which eventually arrives 12 minutes behind schedule, but catches up 5 minutes of its delay along the way, which eventually leads to a 7-minute arrival delay. Our analysis does not allow us to observe these cases. This could be less realistic in case of a network with large distances travelled, both between stations or during one service run; for instance, a night train travelling multiple hours between stations could more easily catch up an accumulated delay. However, due to the short distances travelled within our metro case study network, we can assume these cases to be rare to happen, hence our assumption can be considered realistic. This could change, however, when this same methodology would be applied to delay calculations for longer-distance travel. In this case, additional data such as scheduled vehicle data might need to be taken into consideration.

Another uncertainty lies in the difference between the experienced delays (i.e., directly retrievable from smart card data) and estimated delays, which were needed to determine the departure delay of a trip, enabling a meaningful comparison between refund schemes with departure and arrival delay. However, as can be seen from section 5.4, the estimated arrival delay and experienced arrival delay can sometimes differ significantly. This discrepancy can, as mentioned, be expected to reasonably influence the 'pay rate' of refund schemes, especially with refund schemes that do not make use of automatic reimbursement.

Also, as already briefly mentioned, with the data that is available, it is not possible to always determine which passenger took which metro line. This is due to the fact that several lines in the network are bundled. The extent to which this influences the analyses carried out in this thesis is limited. However, it would have facilitated the fusing of the smart card data with disruption log files, which are also available for the study period.

Finally, (the influence of) scenarios like a service interruption, leading to alternative transport being a viable alternative for a trip that is not possible to take anymore, are not testable with this (data) setup. This could have been a relevant addition as many cities found in the survey in chapter 3 seem to use a refund scheme that also allows taking alternative transport during a service interruption.

We will return to the possible new research opportunities to shed light on these limitations in subsection 7.2.3.

7.2.2. Methodology assumptions

Next to the methodology limitations that we discussed above, we have also made a number of assumptions. These assumptions made might influence the final result in various ways, but also to various extents. We have listed the suspected level of influence, alongside a motivation of the choice, in Table 7.1.

Section	Assumption	Influencing...	to a ... extent	Motivation
5.2.3	Flat fare for refund schemes is $3	KPI results, delay-refund plots	high	Realistic figure (average fare paid over all trips is $3.08), but arbitrarily chosen nevertheless
2.2.2	Departure delay is never smaller than arrival delay	KPI results, delay-refund plots	medium	Small distances, so vehicles making up for delay can be considered rare
5.2.4	Generalised arrival delay application	KPI results	medium	Assumptions partially motivated with literature, but implementation different (trip-based punctuality rather than vehicle-based)
2.3	Using 2023 fares on 2018 data	KPI results, delay-refund plots	low	Proportions of fares most likely remained constant
6.3.4	KPI perceiving for customer and PT operator	'Best' refund scheme	low	Only influencing a possible 'best' refund scheme chosen

Table 7.1: Methodology assumptions

7.2.3. Future research opportunities

As discussed in subsection 7.2.1, we have defined several caveats and/or limitations discovered within our research. We will now determine a number of new research opportunities that this could create. To start with, new research could focus on the most optimal ways to integrate - or refund - alternative transport possibilities in the case of service interruptions. For instance, in case of service interruptions of similar impact, several alternative transport compensation scenarios could be compared against the impacts on passenger satisfaction, which could create more insight in the impacts that taking this alternative transport has for passengers. This could create a useful way of increasing passenger satisfaction in these situations.

Furthermore, as mentioned, to make the aforementioned discrepancy between estimated vs. experienced delays smaller, possible new research could focus on the link of individual passenger behaviour (e.g., walking routes taken) in combination with registered tap-in/out behaviour. This could create more insights in the ways in which delays encountered in, or transferring between vehicles eventually affects passengers using these vehicles. This could be relevant for public transport operators, for instance to determine to what extent it influences the amounts of refunds they can expect, but it could also aid them to further optimise factors like platform to exit walking routes, or even signposting passengers to already have their smart cards ready. The latter might for instance be relevant in a hypothetical case that crowding would occur mainly at smart card gates because many passengers are still searching for their smart card.

A further point of attention is the fact that, when looking at Figure 3.1, delay refund schemes seem to be more common in the northwestern half of Europe than the southeastern half. Although the exact causes for this are unknown, a factor that might influence the presence of a refund scheme might be the level of service reliability. These can be expected to influence each other because a lower level of service reliability might create unacceptable monetary losses for operators with a refund scheme in use. However, this link is far from certain. Therefore, additional research could focus on the link between service reliability and the presence of refund schemes, respectively the delay thresholds that they maintain.

As one of the few references to refund schemes found in literature, Yap (2020) mentions disruptions as being one of the possible causes for an operator to issue a refund. As already mentioned above, the current data available makes it impossible to determine which passenger took which line, hence reliably fusing disruption information with the refund scheme analysis carried out in this thesis would require making additional assumptions, such as the shares of passengers that are split over lines that are bundled. This could increase the knowledge of the relationship between disruptions taking place, delays occurring, and refunds given, which could for instance be useful for a public transport operator searching for the most cost-efficient way to mitigate a disruption taking place.

To conclude this thesis, a major research gap relates to the - possibly speculative - goals of refund schemes that have been mentioned in the introduction. These could be (but are not limited to) influencing the post-purchase customer experience, creating a financial incentive for public transport operators to maintain their punctuality goals, or acting as a proof of confidence to show customers that their destination can be assumed to be reached in time. Despite the analyses of refund schemes and their performance evaluation carried out in this thesis, these do not cast any light on any of these topics which are as such still research gaps, as - to the best of our knowledge - no research has been carried out on these. For this reason, a survey amongst public transport users would be one of the starting points to better understand how public transport customers respond to a refund scheme in use. A survey like this could, for instance, compare scenarios like encountering a delay and receiving the original fare back, as opposed to encountering a delay and receiving a free ticket for another travel. Subsequently, questions could be asked like 'How well do you consider your delay to be compensated for?'. In this way, public transport operators could receive more insights into what their passengers consider important factors when they have experienced a delay. The findings of this survey could possibly be coupled with the KPIs defined and tested in this research, which would enable one to monitor and/or predict customer satisfaction ratings. This could serve as a start for better aligning customer expectations with customer service, which can be considered the main goal of a refund after a delay.

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A

Overview of refund scheme per country/city found

Austria
Vienna
No information found, neither on operator website, nor with additional search queries.

Belgium
Antwerpen (premetro)
No information found, neither on operator website, nor with additional search queries.
Brussels
In the general terms and conditions of the MIVB (operator), the following is stated: if MIVB deliberately committed a mistake, the maximum compensation is one trip, either compensated 'in natura' or by a fee. No further information is provided about this policy (i.e., what is meant by a 'deliberate mistake') and the mere way to find it is to search in the terms and conditions of the operator. Hence, it can be argued that its existence is very unknown. MIVB (2023)
Charleroi
No announcement on their website; policy not promoted by operator – hence, could arguably be very unknown. No refund scheme for single-use cards, only for subscriptions: for a service interruption of more than two hours, a subscription holder can request a refund based on the subscription price paid TEC (2023)

Bulgaria
Sofia
No information found, neither on operator website, nor with additional search queries.

Czech Republic
Prague
No information found, neither on operator website, nor with additional search queries.

Denmark
Copenhagen
Travel guarantee for the metro (English website): "If the metro is delayed for more than 30 minutes and you have to take a taxi or rent a bicycle, an electric scooter or a City Car we cover expenses up to DKK 300." (= ± €40)
Translated version of the Danish website: "If the Metro is reported to be half an hour or more late, we will pay if you have to use alternative transport. Alternative transport can be, for example, a taxi or the rental of a shared bicycle, electric scooter, or shared car. We only cover if the alternative transport is publicly available and is provided by a VAT-registered company with a VAT number. Initially, you have to pay for it yourself, but we will cover your costs with up to DKK 300 if the conditions for reimbursement are met." Very easy to find on the website of DOT (2023)

Finland
Helsinki
"In case of a strike or other special circumstances that have a significant impact on the provision or use of public transport, we will issue refund instructions on a case-by-case basis and publish them on our website. Service disruptions, for example a service not running or not running as scheduled, do not automatically entitle customers to refunds." HSL (2023)

France
Paris
Under the following conditions:
- if a punctuality metric of <80% (calculated as: more than one out of five passengers arrives on their destination with a >5-minute delay) is achieved on a line for >3 months,
- if it can be proven that a traveller with a subscription lives in the area around the affected line

refunds are granted:
- 3-5 months of arrival punctuality <80%: half a month of free traveling
- 6-9 months of punctuality <80%: a full month of free traveling (unless 3-5 months of passes, then half a month)
- 10-12 months of punctuality <80%: one and a half month of free traveling (unless 3-5 months of passes, then half a month, or 6-9 months of passes, then one month)

Île-de-France-Mobilités (2023)
'Reimbursement is therefore not automatic. And the procedure is still little known. In 2021, only a third of the users concerned received compensation, according to an estimate by the Association of transport users AUT / FNAUT Ile-de-France, given to the Parisian.' Libération (2023)
Marseille
No information found, neither on operator website, nor with additional search queries.
Lyon
No information found, neither on operator website, nor with additional search queries.
Toulouse
No information found, neither on operator website, nor with additional search queries.

Germany
Berlin
Current refund scheme: with a delay of >20 minutes of arriving at a destination, a free ticket is granted, or with a subscription, a refund is granted. For delays between 23:00-05:00h, a taxi is refunded < €25.00. BVG (2023)
In use since 1997, however, hardly known. ±1000 requests in 2015, of which ±50% granted. Fülling (2023)
Online form promised, however, as of February 2023 not yet implemented Ohmann (2023)
Easy to find.
Hamburg
For delays (concerning the arrival at a destination) exceeding 20 minutes, 50% of ticket fare refunded, or with subscriptions, a relative amount to the average usage of the subscription.
Needs to be requested manually, and together with the original ticket, needs to be presented at a service desk, after which the amount is paid in cash.
For subscriptions, the maximum refunded amount is capped at half of the original purchase fare.
Easy to find. HVV (2023)
München
More or less identical to Berlin. >20 minutes delay: price of a day ticket (i.e., €5) is refunded. In case of the last transfer missed: taxi costs < €25 refunded MVG (2023). Since April 2000 in use Merkur (2023).
Not specified whether >20 minute departure delay or >20 minute arrival delay.
Köln, Düsseldorf, Dortmund, Essen, Duisburg
General 'mobility guarantee' for the entire state of Nordrhein-Westfalen:
For any delay exceeding 20 minutes (and a valid ticket in possession), a taxi, sharing bike/car or long-distance train can be used. Maximum reimbursement between 05:00-20:00: €30, between 20:00-05:00: €60. The transfer into the alternative transport mode should be within 60 minutes of the original planned departure time. mobil.nrw (2023) Wernig (2023)

No refund is granted, however, for a delay occurring during the ride.
Frankfurt a. M.
Rhein-Main-Verkehrsverbund policy: with > 10 minutes arrival delay, full fare (capped at €6) is reimbursed, can be collected in cash at a service desk. RMV (2023)
Stuttgart
With an expected delay of >20 minutes for reaching destination, taxi refunded up to €35 (or €50 with a subscription), however, only if there is no suited option of reaching the destination by other means of public transport. SSB (2023)
Hannover
Refund of the full paid fare, or 50% of a day ticket, of €5 for subscription holders, for departure delay > 20 minutes (or an expected arrival delay of >20 minutes). For waiting >60 minutes or between 23:00-5:00, taxi costs of maximum €25 are reimbursed. GVH (2023)
Nürnberg
Refund of the equivalent of a single-use ticket 'Preisstufe A' for arrival delays exceeding 15 minutes. Missed transfer in the evening (i.e., after 20:00) or weekend: taxi costs refunded VAG (2023)

Greece
Athens
No information found, neither on operator website, nor with additional search queries.
Thessaloniki
No information found, neither on operator website, nor with additional search queries.

Hungary
Budapest
No information found, neither on operator website, nor with additional search queries.

Italy
Apparently, a refund scheme for the entirety of Italy exists, however, not findable on website of any operator. If indeed in use: single ticket price refunded or a percentage of a subscription for subscription holders. Delay thresholds are departure-related: 30 minutes for 'urban public transport', under which metro systems would arguably fall, and 60 minutes for 'local public transport'. Quatraro (2023) Romanazzi (2023)
However, with the exception of Turin, having its own refund scheme, no information was to be found on the policy whatsoever on the websites of the individual operators.
Rome
No information found, neither on operator website, nor with additional search queries.
Milan
No information found, neither on operator website, nor with additional search queries.
Naples
No information found, neither on operator website, nor with additional search queries.
Turin
Refund policy in use: €3 for > 60 minutes of metro departure delay. Uncertain how this interferes with the apparent Italy-wide policy in use. GTT (2023)
Genoa
No information found, neither on operator website, nor with additional search queries.

Netherlands
Amsterdam
Taxi service for:
- last service not arriving 20 minutes after planned departure
- any >60-minute delay without other forms of PT
- missing transfer from a delayed last service

Easy to find. GVB (2023)
Den Haag
Any >30-minute delay: €3
No refund for pre-announced delays or force majeure.

Only for trams, not for buses.
Maximum term 4 weeks after delay, maximum payment term 2 weeks.
Easy to find HTM (2023)
Since 2015, the paid fare is reimbursed for any delay on the RandstadRail network exceeding 30 minutes Roos (2023). It is unknown at which moment this policy has been ‘merged’ with the HTM policy.
Rotterdam
Any >30-minute delay: smartcard for two hours
Any >60-minute delay: smartcard for one day or taxi costs
Two >20-minute delays within one week: smartcard for two hours
First or last service not coming or delayed >10 minutes: smartcard for two hours, or replacement service
For bus, tram, and metro
No refund for pre-announced delays or force majeur
Easy to find RET (2023)
Utrecht
No information found, neither on operator website, nor with additional search queries.

Norway
Oslo
For delays >20 minutes: costs of alternative transport (taxi, car or other alternative means of transport) up to 750 NOK (€67,57) are refunded. Supposedly, departure delay rather than arrival delay, although this is not explicitly specified Ruter (2023)

Poland
Warschau
No information found, neither on operator website, nor with additional search queries.
Gdansk (Tricity Rapid Transit Rail)
No information found, neither on operator website, nor with additional search queries.

Portugal
Lisbon
No information about refund scheme to be found on operator website, however, on a forum, one customer complaining about taking a replacement taxi and being reimbursed the ticket fee (€1,50) after waiting 25 minutes. Queixa (2023)
Porto
No information found, neither on operator website, nor with additional search queries.

Romania
Bucharest
No information found, neither on operator website, nor with additional search queries.

Spain
Madrid
Refund scheme for single-use or 10-ride tickets, where the price is refunded if:
- Service is suspended
- Headways of metros exceed 15 minutes, where normal service envisions headways < 7.5 min
- Headways of metros exceed 20 minutes, where normal service envisions headways ≥ 7.5 min

Madrid (2023)
However, the refund does not apply to season tickets, which is considered unfair by Garijo (2023)
This ‘unfairness’ was signalised in August 2019 – no changes seem to have been made so far.
Barcelona
No information found, neither on operator website, nor with additional search queries.
Valencia
No info, although in 2007, information was found on some individual cases of compensation 20minutos.es (2023)
Sevilla

No information found, neither on operator website, nor with additional search queries.
Malaga
No information found, neither on operator website, nor with additional search queries.
Palma de Mallorca
No information found, neither on operator website, nor with additional search queries.

Sweden
Stockholm
Compensation of up to SEK 1,315 (€116) for alternative traffic if estimated arrival delay would be >20 minutes. For taking car, SEK 18.5 per mile, i.e.: €0.16 per km, parking costs also reimbursed.
No alternative transport used? For >20 minutes delay: 50% refunded, for >40 minutes 75% and for >60 minutes 100%.
If traveling with a period ticket, a price per trip is calculated based on how many trips a traveler with such a ticket makes on average.
In case of alternative transport used but no ticket bought yet: original ticket price deducted from the compensation. SL (2023)

United Kingdom
London
Refund scheme in use for delays >15 minutes happening on the Undergrond/DLR and >30 minutes on the Overground/Elizabeth line Automatic reimbursement could occur within 48 hours; otherwise claiming the refund can take place automatically. The full fare is compensated for. London (2023)
Manchester "Metrolink may make appropriate refund and/or compensation arrangements" if service performance cannot be maintained. However, no more specific information is given. TfGM (2023)
Plans to introduce a refund scheme 'in the future' (Feb 2018), however, no signs of it. Stuart (2023)
Newcastle (Tyne & Wear Metro) Single journey price paid back with arrival or departure delays > 15 minutes Tyne and Wear (2023)
Glasgow
Explicitly stated on website of operator: no refund scheme

United States
Boston
Refund scheme abandoned Railroading (2023)
New York One successful case of refund described York (2023). No further evidence of successful repays found, subway service seems notoriously unpunctual, and the passenger loss hours have been described in Office (2023)
Chicago
Explicitly stated on operator website: no refund policy
Cleveland
No information found, neither on operator website, nor with additional search queries.
Philadelphia
Cancelled; used to be 15 minutes arrival delay but was cancelled over the summer of 2016 following a large surge in delays due to maintenance works News (2023).
Smartcard introduction was mentioned as a possible date for reinstating a delay refund. Mondon (2023) However, as of the moment of writing, no information could be found about it.

Canada
Toronto
No information found, neither on operator website, nor with additional search queries.
Montréal
No refund scheme in place, although there is public pressure for applying one, but latest news regarding this dating from 2018. No more recent information could be found Cambron-Goulet (2023) Radio-Canada (2023).
Vancouver
No information found, neither on operator website, nor with additional search queries.

B

Station code index

To clarify which stations were meant in Table 6.5 in section 6.3, in Table B.1, the station codes are shown.

ID	Name
1	Metro Center
2	Farragut North
3	Dupont Circle
4	Woodley Park-Zoo/Adams Morgan
5	Cleveland Park
6	Van Ness-UDC
7	Tenleytown-AU
8	Friendship Heights
9	Bethesda
10	Medical Center
11	Grosvenor-Strathmore
12	White Flint
13	Twinbrook
14	Rockville
15	Shady Grove
16	Gallery Pl-Chinatown
17	Judiciary Square
18	Union Station
19	Rhode Island Ave-Brentwood
20	Brookland-CUA
21	Fort Totten
22	Takoma
23	Silver Spring
24	Forest Glen
25	Wheaton
26	Glenmont
27	NoMa-Gallaudet U
28	Metro Center
29	McPherson Square
30	Farragut West
31	Foggy Bottom-GWU
32	Rosslyn
33	Arlington Cemetery
34	Pentagon

35	Pentagon City
36	Crystal City
37	Ronald Reagan Washington National Airport
38	Braddock Road
39	King St-Old Town
40	Eisenhower Avenue
41	Huntington
42	Federal Triangle
43	Smithsonian
44	L'Enfant Plaza
45	Federal Center SW
46	Capitol South
47	Eastern Market
48	Potomac Ave
49	Stadium-Armory
50	Minnesota Ave
51	Deanwood
52	Cheverly
53	Landover
54	New Carrollton
55	Mt Vernon Sq 7th St-Convention Center
56	Shaw-Howard U
57	U Street/African-Amer Civil War Memorial/Cardozo
58	Columbia Heights
59	Georgia Ave-Petworth
60	Fort Totten
61	West Hyattsville
62	Prince George's Plaza
63	College Park-U of Md
64	Greenbelt
65	Gallery Pl-Chinatown
66	Archives-Navy Memorial-Penn Quarter
67	L'Enfant Plaza
68	Waterfront
69	Navy Yard-Ballpark
70	Anacostia
71	Congress Heights
72	Southern Avenue
73	Naylor Road
74	Suitland
75	Branch Ave
76	Benning Road
77	Capitol Heights
78	Addison Road-Seat Pleasant
79	Morgan Boulevard
80	Largo Town Center
81	Van Dorn Street
82	Franconia-Springfield
83	Court House
84	Clarendon
85	Virginia Square-GMU
86	Ballston-MU
87	East Falls Church

88	West Falls Church-VT/UVA
89	Dunn Loring-Merrifield
90	Vienna/Fairfax-GMU
91	McLean
92	Tysons Corner
93	Greensboro
94	Spring Hill
95	Wiehle-Reston East

Table B.1: Station codes

C

Delay-refund plot with outliers

In Figure C.1, a plot of the delays vs. refunds with outliers can be seen.

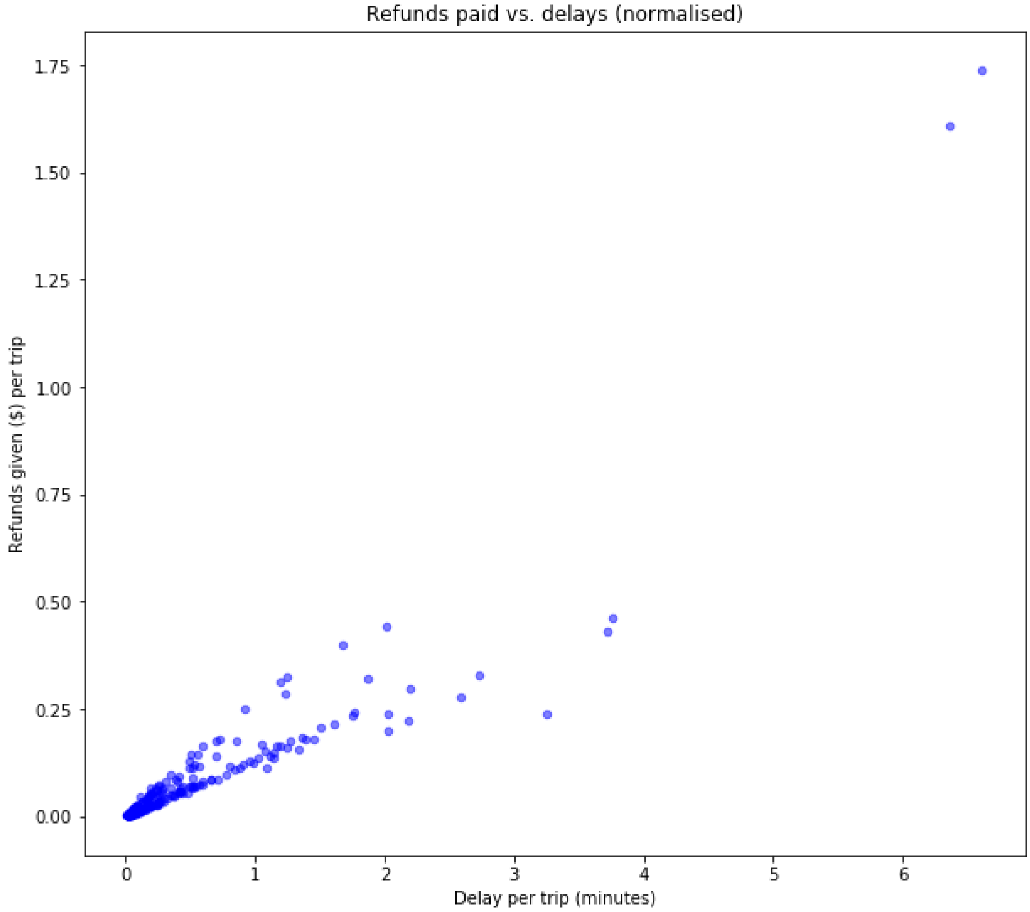

Figure C.1: Delay-refund plot with outliers